

AMBIENCE'11 PROCEEDINGS



Ambience'11

...WHERE ART, TECHNOLOGY AND DESIGN MEET

PROCEEDINGS 2011

BORÅS SWEDEN

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Welcome to Ambience'11

The Ambience'11 conference focuses on the intersections and interfaces between technology, art and design. The first international conference in the Ambience series was held in Tampere, Finland in 2005. In Tampere the basic theme was "Intelligent Ambience, including Intelligent Textiles, Smart Garments, Intelligent Home and Living Environment". In Borås 2008 it was "Smart Textiles – Technology & Design" in focus and in Borås 2011 it is the new expressional crossroads where art, design, architecture and technology meet.

With a foundation in artistic practice the conference is organized as a meeting place where art, design, architect and technology communities can come together to discuss and share ideas on the interfaces between art and technology and to bring new ideas back to their own community.

The conference includes sessions for paper presentations as well as an exhibition for the presentation of art, design and architectural work. The proceedings collect all papers accepted for oral presentation at the conference together with abstracts of the keynote presentations.

We are happy to welcome contributions in the areas of digital architecture, interaction design, new media art and smart textiles from 19 countries.

We are also happy to welcome the conference keynote speakers: Alex Adriaansens, V2 Labs in Rotterdam, Nancy de Freitas, Auckland Univeristy and Jenny Sabin, Penn State University.

We expect the conference to nourish ongoing discussions and open up new discussions and critical reflections on the role of technology, craft and material thinking in artistic work. We hope you will enjoy these days in Borås and that the proceedings will help to further immerse you into issues raised during the conference and perhaps also provide unexpected inspiration for future work.

Ambience'11 is organized by The University of Borås in cooperation with Tampere University of Technology (www.tut.fi) within the Smart Textiles Initiative (www.smarttextiles.se). The conference will take place at Pulsen, an old cotton warehouse which has been renovated into a modern meeting place. The Ambience'11 Exhibition will be shown at the Museum of Textile History which gives visitors an impression of the industry that once established Borås as Sweden's leading textile centre.

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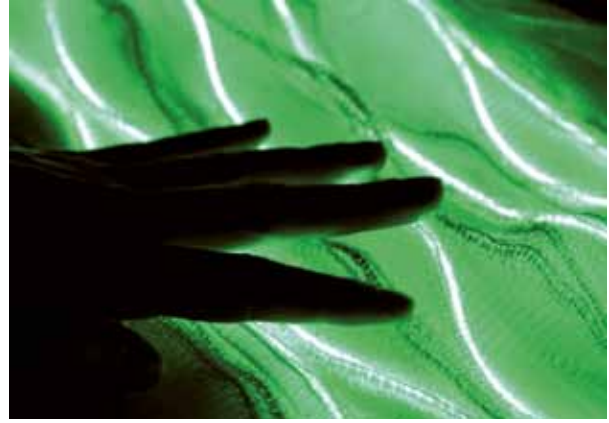
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Science for the professions

The University of Borås is a modern university with six departments. We manage educations in Library and Information Studies, Business and Informatics, Fashion and Textile Studies, Behavioural and Education Sciences, Engineering and Health Sciences. The campus is located in the centre of the city and we have 15 000 students and 650 employees.

The Swedish School of Textiles in Borås has honoured the regions century old traditions in textiles by developing a modern, up-to-date centre for education in textiles. The Swedish School of Textiles has developed into a national and international resource centre and has become a natural meeting place for students, scientists, designers and professors from all parts of the world. The school has education on graduate and post graduate levels in all areas of textile and fashion i.e. design, technology and business & management as well as research in all of those areas.

KEYNOTE SPEAKERS

Alex Adriaansens



Alex Adriaansens studied at the Royal Academy for Art and Design in Hertogenbosch (NL). With Joke Brouwer he is the founder of V2_ (1982). Art, science and technology and how they critique and construct the realities we live in, and how we can act and interact in them, is a major point of interest in his presentations. As the artistic director he's also responsible for the DEAF biannual festival one of the major European festivals on art, science and technology. Alex Adriaansens is active in several advisory groups (education, arts organizations, policy makers), advisory boards (Transmediale, D; Theatre in Motion, CN; ISEA2010, D) and has been a guest curator for several exhibitions (Brazil, Taiwan, China, Norway). He has given presentations at festivals, universities, workshops a.o. Laboral (ES), Moma NY, ICC (J), NTU University (Singapore), Tsinghua University (CN), ITAU Cultural (Br), and Elektra (CDN).

ABSTRACT—The power of things

In the last decennia we can see a shift from an object oriented world model to a world model based on relational thinking, a worldmodel where objects connect to other objects and form dynamic networks. From interactions in these networks structure and Form emerges (social, cultural, political). Understanding The Power of Things and how they interact and generate Form, or in other words how they constantly transform the physical world has become a major research domain in many practices.

Over the last years fundamental debates are taking place about the way we have historically organized our world in a social, economic, political and cultural sense and around major institutions like the State, Church, and the Parliament a.s. Institutions and the way they function, how they are organized, and what their role in society is and should

be, has become more and more central in these debates since our societies are changing rapidly because of an ever expanding technological culture that characterizes itself by global networks and communication technology. The role of information and communication technology in a globalizing as well as localizing world, is very much shaping how we experience ourselves and the world we are part of, and how we can act and interact in it.

This is the contemporary context within which V2_ reflects its interdisciplinary artistic practices and itself. For V2_ the experiment, and having a focus on research and the experiment is therefore a key issue in its program, this to be able to research, critique and design our technological culture and of course ourselves. This presentation will show you some of the interdisciplinary V2_ practice and the concepts and collaborations around which it shapes itself over time.

Jenny E. Sabin



Sabin's work is at the forefront of a new direction for 21st-century architectural practice one that investigates the intersections of architecture and science, and applies insights and theories from biology and mathematics to the design of material structures. Sabin taught design studios and seminars in Architecture at the University of Pennsylvania, 2005-2011. She is Principal of Jenny Sabin Studio, an experimental architectural design studio based in Philadelphia. She is co-founder of LabStudio, a hybrid research and design network now based at Cornell University, University of Pennsylvania and Stanford University, together with Peter Lloyd Jones. She is also a founding member of the Nonlinear Systems Organization, a research group started by Cecil Balmond, where she was Senior Researcher and Director of Research. Jenny holds degrees in Ceramics and Interdisciplinary Visual Art from the University of Washington and a Master of Architecture from the University of Pennsylvania where was awarded the AIA Henry

Adams first prize medal and the Arthur Spayd Brooke gold medal for distinguished work in architectural design, 2005.

ABSTRACT — Between Architecture and Science: Material Analogs

Collaborations between architects and scientists offer up venues for productive exchange in design while revealing powerful models for visualizing the intangible. Sabin's collaborative research, teaching and design practice focus on the contextual, material and formal intersections between architecture, science and technology. Through the visualization and materialization of dynamic and complex datasets, Sabin has generated a body of speculative and applied design work that aligns crafts-based techniques with digital fabrication alongside questions related to the body and information mediation. This talk will look at intersections between architecture, computational models, textile structures and biology through multiple modes of working and collaborating. The material world that this type of research interrogates reveals examples of nonlinear fabrication and self-assembly at the surface, and at a deeper structural level. In parallel, this work offers up novel possibilities that question and redefine architecture within the greater scope of generative design and fabrication.

Nancy de Freitas



Nancy de Freitas is an academic and professional artist based at the Auckland University of Technology in New Zealand where she is Associate Professor in the School of Art and Design and Programme Leader of the Master of Arts Management. She is Editor-in-Chief of the international journal *Studies in Material Thinking*. Nancy received her early education in Trinidad in the West Indies. She completed her undergraduate and postgraduate degrees at the Ontario College of Art and Design and the University of Auckland, respectively. Her installation works have been exhibited in solo and group exhibitions in

Canada, Australia and New Zealand. Nancy has been the recipient of several art awards, a Canadian Government Faculty Enrichment Award and Artist in Residence in three studio/research residencies based in Auckland, New Zealand. De Freitas has been involved in several research initiatives including the Higher Education Research and Development Society of Australasia, and served for many years on the Board of Directors of the Te Tuhi Centre for the Arts, the public art gallery for Manukau City, New Zealand. She has been invited to lecture internationally on art and design practice-led research and material thinking methods. Host Institutions include Parsons the New School for Design, NYC; Faculty of Fine Arts, Concordia University, Montreal; OCAD University (Ontario College of Art and Design), Toronto; Faculty of Fine Arts, York University, Toronto; Faculty for the Creative and Cultural Industries, University of Hertfordshire, UK; Queensland University of Technology, Brisbane; Massey University, Wellington and the Design School, UNITEC, Auckland. Her current research interests include themes on professional education for the design, creative and cultural sectors, the language of research reporting, the effects of documentation/reflection practices on professional development and 'material thinking' approaches.

ABSTRACT — What's New About Material Thinking?

The concept of material thinking is re-examined as a core artistic and design tool for the 21st century. The context is the conference theme, which is focused on the intersections and interfaces between technology, art and design. To this I will add another element, the environment, which denotes the material/physical/spatial dimensions of our experience as well as the human dimensions: the social, cultural and spiritual. Artists and designers understand that the nature of their experiments and interventions is dynamic and emergent. They are familiar with the experience of project developments that change the pattern of their thinking even before they have an insight of the point of completion or a resolved outcome. These emergent and interdisciplinary working methods open multiple pathways while subjective and interpretative ways of thinking, integral in creative processes, add further complexity and richness to the process. This presentation outlines four standpoints from which we might consider material thinking. They are separate but related frames through which I will attempt to articulate a working concept that may be broadly useful across academic and research domains as well as in the creative industry sector where the value of entrepreneurial activity is most highly prized.

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Digit / Digital@Lab
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INTERACTION DESIGN

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Clemens Winkler

Woven Light
Jan Carleklev

Stringling
Stephanie Carleklev

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Mask
Marjan Koorshnia

Articulated Behavior

Computational Methods for the Generation and Materialization of Complex Force-active Textile Morphologies

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ABSTRACT

A compelling yet challenging aspect of textiles in forming architectural space is the inextricable relationship of the textile structure and the overall geometry. When considering the use of textiles as structural surfaces, where a force of tension is applied to develop stable structures, this condition is most critical to consider. This paper will describe a material behavior-based computational methodology for the design and fabrication of complex tensioned textile forms through the use of Particles Systems and material-based translational algorithms.

Keywords

Tension-active, particle system, springs, topology, fabrication, computational design, behavior-based design

INTRODUCTION

In working with textiles, geometry is always a by-product of the material structure. One cannot define the geometry before first understanding the capacities of the material. When setting a textile as a structural surface, this is an even more significant conditions. The route by which the relationship of material and form is studied and resolved is pivotal as it must accurately mime the performance at full and final scale.

Form-finding, exemplified in tensile structures from Frei Otto, serves as a viable design method whereby scaled models simulate full-scale material and structural behavior (Fig. 1). Computationally, this is most directly translated into the use of Finite Element Analysis for structural form-finding.[9] From a design perspective, methods in the use of Particle Systems have proven valuable for approximated form-finding experiments.[7] Particle Systems are computational physics-based engines which simulate primary forces such as gravity, tension, compression, drag, magnetism, and pressure. While it computes the interaction of these behaviors quite efficiently, it does not reflect the

precision and accuracy in material properties that physical form-finding and FEA allows. But, through utilizing the dataset within a Particle System modeling environment, mainly that of geometry and force, a methodology of form-force simulation and data translation produces a viable process for the generation and fabrication of complex tension-active textile arrangements.



Figure 1: Form-finding model by Frei Otto for the design of Stuttgart21 Railway Station with Ingehoven Architects.

The use of Particle Systems to replicate physical form-finding methods has been well documented; initiated, arguably, with Axel Killian's CADenary software replicating Gaudi's hanging-chain methods. The evolution of these algorithms for simulating fundamental physics has seen models formed via the multitude of forces calculable with a Particle System engine. The approach seeks geometry organization, not through discreet rules, but through emergent behavior of interacting forces forming an equilibrium state. The value, though often unseen, is that these resulting models hold information, not only of geometric description, but of dynamic force-active properties, critical for materialization and an understanding of the entirety of the interrelated system [2].

Behavior-based computational form-finding is structured by three primary principles: simulation of force, modeling of topology, and translation from geometry to materialization. With each aspect comes design opportunity. As a design

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environment, while constrained, it allows for a high degree of flexibility in specifying material descriptions from and within the generated force diagrams. A behavior-based design environment, as such, will not predict exact material specifications but will provide basic properties related to force and relative material elasticity, which through geometric and mathematical translation prove pivotal for linking the computational model to physical production. Dissecting the information in topology and force, and translated against real material properties, a direct transference from computational model to physical fabrication and form can be made. This paper describes a series of case studies in which each of these aspects of the behavior-based design framework as avenues for design articulation and construction of highly complex and articulated tension-active structures.

COMPUTATIONAL FORM-FINDING

Much has been developed in the field of physics-based algorithms for architectural purposing. Many Java-based solvers exist [3,5,10] which are accessible through programming environments such as Processing. While libraries such as Kangaroo for Rhino's Grasshopper make for visually scriptable physics-based simulation environments. Arguably, they are primarily replicating in an efficient manner the type of simulation for structural properties that a Finite Element based software produces. But, working upon simpler principles, the inputs are minimized and a path towards exploration is possible. For instance, a 'spring' is a commonly used element in physics-based modeling. As a part of a Particle System the spring is solved following Hooke's Law of Elasticity. This is a linear equation which relates force to the displacement of an element from its original length including a strength factor. Materials under force do not behave in a linear fashion, but for a design simulation, such an equation is ample. Physics-based solvers, while not always functioning to produce absolute precision, provide a feasible guide and large dataset of information when dealing with the interaction of force and material properties.

These distinctions in computational methods between design simulation and engineering simulation is significant when viewing it from the perspective of computational process. The distinction lies between simulation as design validation and simulation as an avenue for experimentation. Simulation, in relation to structural analysis of architectural forms, commonly serves as either the confirmation of a particular design scenario or the deduction of the most basic principles of a structure system. Where design occurs is in between these two ends. In dealing with simulation as an avenue for relating structure, form and material, it is not possible to be truly 'bottom-up', where the most basic principles can be discovered and then iteratively executed to develop a whole system. Rather, it is in exploring the fundamental principles that design occurs. When these principles require the knowledge and implementation of

behavior at the level of material and interacting forces, then the computational process has to be founded upon principles which underlie these behaviors. The computational framework then serves to generatively produce and test the ranges of interaction that are relative to a particular design context and architectural system as a whole.

PRINCIPLES FOR BEHAVIOR-BASED COMPUTATION

As mentioned before, the principle aspects of a behavior-based computational methodology encompass force simulation, topology and material translation. These are all inextricably related and inextricably bound to the physical performance of the system being produced. In particular, this reflects, again, the shift in perspective for computational process from one where geometry is primary and abstract to one where force, expansiveness of dataset and alignment to material performance are equally critical. In this sense, geometry is a by-product, not the sole pursuit. So, within the principles of behavior-based computation are not only issues of tool development, but also of larger issues in how the design framework serves as a specific emulator of physical system performance, yet allows for investigation and experimentation within the constraints of the system.

In comparison to conventional computational processes, when engaging behavior as a design variable the definition of abstraction is vital. Typically, abstraction is a necessity in computational design. It allows the freedom for geometry to move without constraint to materiality. But, this means that the geometry and the process that generated it stay at that level of abstraction; data is simply an overlay. In a behavior-based process, an abstraction of force and material may initially exist, but through iterative development, specificity must emerge for the process to be about feasible results and provide information to materialize such results. From this perspective, behavior-based design is of both a meta-set of procedures and a structure of computational processes.

In the research described in this paper, the meta-process is one which engages the concept of prototype on both a physical and computational level. From knowledge-based design, we understand the 'prototype' not only as a physical example which is exemplary of an entire branch of studies, but they are parameterized episodes establishing the backbone of a generating system. [4] The episode can be a sequence of steps to materialize a structure, or it can be a sequence of algorithms executed to produce a particular result. The episode is not a 'case' as a finite condition which holds valuable information only about itself. Rather, the sequences of events hold parameter sets which begin to design and specify the constraints in which a particular branch of solutions is possible. In this research, this approach is reflected in a meta-process by which multiple cycles of exchange between computational form-finding and physical construction produce continuous development

in the knowledge of the system, its capacities, and precision by which its form and performance are generated.

Computation of Tension-Active Systems

Computationally, tension-active systems are formed via vectorized force elements (springs) recognizing fundamental material rationales, in their internal capacity and overall assembly logic. Properties such as stiffness and relative response to compression or tension force are held within each individual element. Overall assemblies can reflect material dynamics with uniform or anisotropic structural qualities. This can be done through varying the topology of the network of elements or locally manipulating the parameters of the individual elements. Conventionally, this allows for the production of varying structural capacities between the internal field, bounding edges, and overlapping seam conditions within a textile assembly. Ultimately, it allows for highly intimate control over the relationship of a material's structural capacity, its relationship to the response of force being applied to it, and subsequent articulation of the resulting structural form.

As structurally defined surfaces, precision and exaction of the material properties, assembly constraints, and stability against external forces is vital [6]. However, this is something that cannot be directly coordinated within the simple parameters or solvers that drive a Particle System. While the Particle System can be modified and further constrained to define particular ranges of elastic materials, complete specification would limit the computational efficiency of the method and remove the process for being an iterative and investigative one. The projects described in this paper elaborate upon a strategy that, despite the indirect relation between computational behavior and material behavior, provides for calculated design opportunities through translational algorithms which harvest the full dataset of geometry and force behavior embedded in the computational form-finding environment in order to exact materialization and assembly.

In the material make-up of the system, a significant variant exists between the performance of a fixed mesh and a woven or knitted surface. At an architectural scale, there is also the distinction of a 'membrane'. As a composite material that is coated, it acts more like a non-elastic surface material than it does a woven textile. The material difference permeates various aspects of a tension-active system in how force flows through the material and how the data of force and geometry is translated into templates for cutting, assembly and pre-stressing (the application of tensile-force to the entire structure at full scale).

In the computational environment, these material distinctions are primarily captured within topology. Within a fixed mesh, force is resolved individually at each fixed node. The pathway of force can only travel through the pathways of the open mesh material. In a knitted or woven surface, where the overlap of fibers is not fixed, tension will travel across the entire surface until it reaches equalization

in force. While a surface will try to equalize force, a mesh works to find a balanced equilibrium of forces. A surface can be approximated with a regular grid of U and V springs to approximate the warp and weft structure of a material. By contrast, an open-mesh can accomplish many variations in topology and still realize a tension-equilibrium form (Fig. 2). These constraints are necessary to indicate materialization, but much can be accomplished by varying the parameters within these prototypical cases.[1]

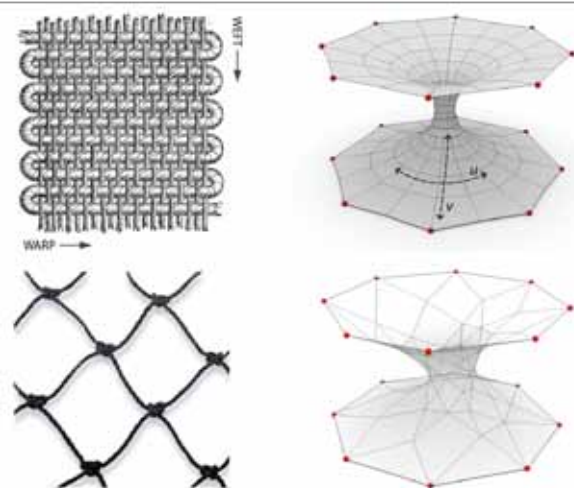


Figure 2: Distinction between a textile and fixed mesh in relation to computational topology. A tensioned surface is most easily approximated with a U/V type grid of springs, while a tensioned open mesh can be generated with a completely variable topology.

These instances not only provide for some material recognition in the design generation process, but they also follow the logic of basic Finite Element analysis for tension-active systems. For an open mesh, the model is constituted of a series of discrete elements, or bars, which define cables spanning from node to node. For a continuous surface, force is controlled via the difference in parameters of the U versus V direction. Therefore, often, a quad mesh is utilized to maintain the logic for these parameters.[8]

CASE STUDIES

The following sequence of studies examine the variables as described earlier: force description, topology of elements, and translation to material. The sequence moves from the development on an entirely open mesh tensioned structure, to a tensioned surface made of textiles with varying internal structure, to an integrated open mesh and surface system developed into a highly complex geometric tensioned form.

Complex Mesh Topologies

In examining topology, two main factors were considered, the variation of interconnected elements to create a complex overall form, and the variation of force across the network of elements. For materialization, the entire network was transformed into a set of interconnected polyester cords,

which had a moderate ratio of elasticity to strength. In the range of forces that the model would undergo, the material stretches up to 200%. A particular aspect in this set of experiments involves management of the complex topology. The stressed (or stretched) condition of each element in the computational model is translated to determine its unstressed length. Simultaneously, the force/material data maintains its location and logic within the topology so that sequences of elements can be linked together to create the overall textile structure.

While the local topology is primarily regular, with a 4-way connection at each node defining a dia-grid type pattern, the global shape is more complex (Fig 3). The system is comprised of three individual cylindrical networks. Varying the manner in which the boundaries of these networks are connected produces the overall complex shape. Computationally, the cylindrical networks are defined as 'objects', a classification and data structure which is carried all the way through to the sequence for fabrication and assembly (Fig 4 and Fig 5).

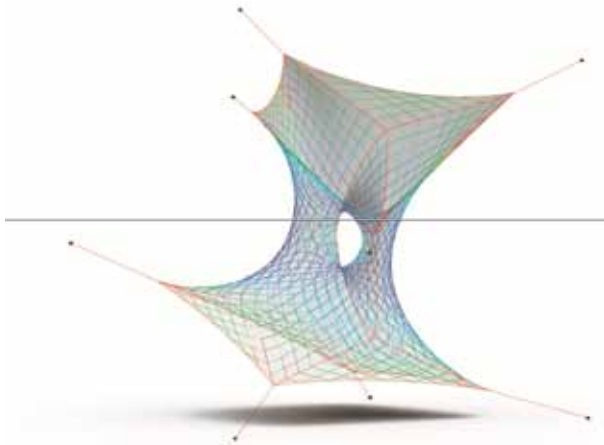


Figure 3: Complex Mesh Topologies. Sean Ahlquist, Institute for Computational Design, University of Stuttgart, 2011.



Figure 4: Mapping for Complex Topology. Data for force and association is mapped for the entire topology.



Figure 5: Fabrication of Complex Topology. The dimensioning of elements is driven via digital testing of the material strength. Mapping and association is dictated by the data structure of the computational model (n:i;j).

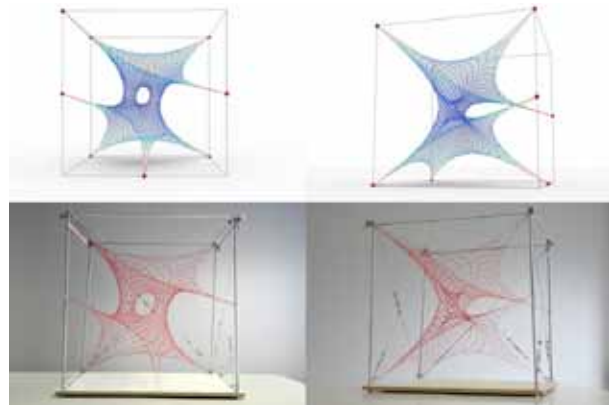


Figure 6: Comparison of computational model and physical prototype.

The model in its tensioned state mimics the form and structural performance as defined in the computational model (Fig6). In analysis, what is elusive is the particular form distinction of the surface 'ridges' along the front of the geometry. Computationally, these ridges are defined by two sets of strengthened springs, indicated by the two red pathways in the model. As the translation of the model from computation to material is not discreet, this geometric characterization cannot be literally carried through. It is only in the treatment of the specifically varied elements that this geometric ridge can emerge. Further research is being done to produce such unique conditions within a continuous mesh, between more precise calibration of material performance and introduction of varying material types.

Varied Surface Structure

As a part of the Digital Crafting Workshop 3 – How to Brace, run by Mette Ramsgard Thomsen of CITA and Sean Ahlquist of the ICD, experiments were done in tensioning textiles constructed of variable internal structures. Most tensile structures are constructed of textiles or membranes which have a very constant or equal ratio of performance in the warp and weft directions. For this workshop, and with this featured case study, the textile is highly varied and

tested to determine its resultant behavior under tensile loading.

The textile developed utilized a single type of thread but varied the knitting structure to create more and less dense areas (Fig 7). The material was fabricated on a CNC knitting machine at the Kolding School for Design.

To look directly at the material behavior, the overall geometry is a simple tensioned cylinder. Utilizing the data in force and geometry, panels are generated from the computational model (Fig 8). This step already introduces an abstraction of the material being generated. The algorithm for panelization uses data for a uniform material as input. Therefore the exact performance of the differentiated material is not being calculated in this step.

In some initial studies with this type of variation in material structure, it was identified that the method of manufacturing had a significant influence into the material behavior. The cutting and textile structure templates produced from the computational model assume a material element with no internal force – an element at rest. This step is called compensation and develops, obviously, a smaller element so that when tension is applied it expands to its geometric form exhibited in the computational model. But, in the instance of this project, the behavior was activated in the process of manufacturing. The variation in knitting created areas varied in elongation (Fig 9). So, the element was not static in its initial state. It housed a certain amount of force internally, therefore did not match dimensionally to the initial input template size that was produced from the machine.



Figure 7: Varied Structure Textile generated on a CNC knitting machine.

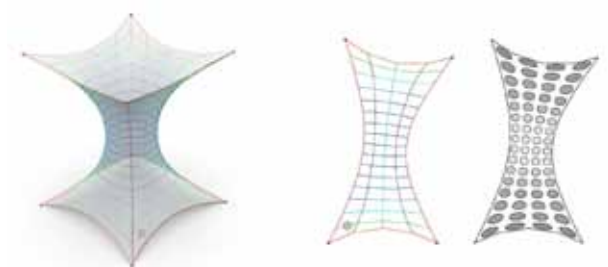


Figure 8: Panelization for Varied Surface Structure. Generated from a basic tensioned cylinder, a cutting template for the panels is generated and then a pattern applied to define variation in the knitting structure.



Figure 9: Internal behavior produced via knitting logic. The change in structure induced a certain behavior.

Because of the unpredictability of material behavior through the fabrication process, the resulting tensioned textile assembly was far from the initial description in the computational model. What was deduced, though, was that this particular material structure behaved more like a tensioned open mesh than a continuous surface. The force expressed itself primarily in the dense knitted areas, and only upon hitting its tensile limit did it pass force into the more open knitted areas (Fig 10).

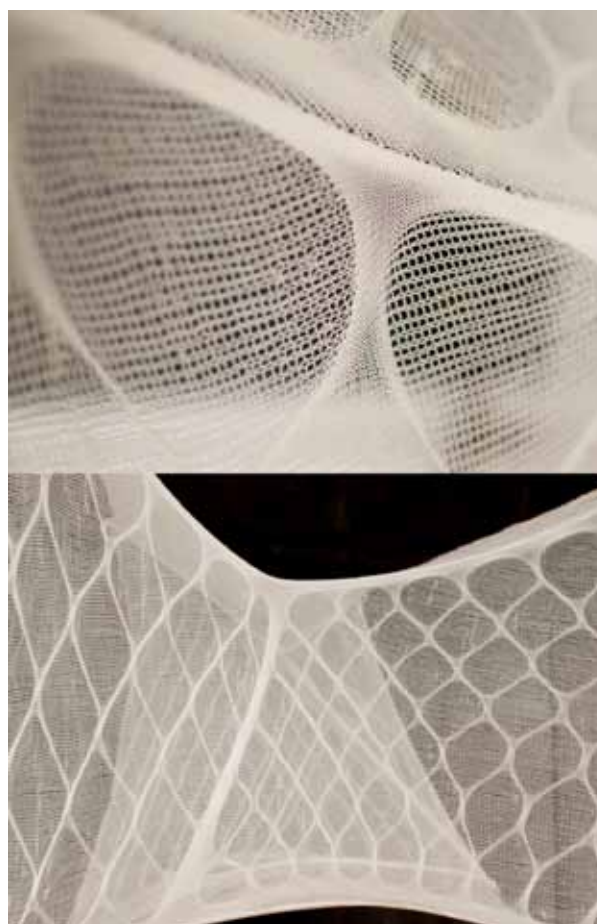


Figure 10: Varied Surface Structure. Paul Nicholas , Ali Tabatbai, Felicia Davis , Claus Pederson (Mette Ramsgard Thomsen CITA, Sean Ahlquist ICD), Kolding Design School, 2011.

Hyper-Toroidal Integrated Topologies

This project addresses one of the most challenging aspects of tension-active systems: the transfer of tension-forces through intensely complex geometries comprised of varying materials. Often, tensile structures follow one of three different types: saddle, conical, or ridge/valley (Fig 11). One main consideration for this is that they develop continuous uninterrupted surfaces which allow the flow of forces to move equally and in equilibrium. Introducing variation into this challenges the ability to calibrate and distribute tension forces. Through a series of steps in developing complexity in tension-active forms, this project exhibits the ability to generate and fully tension complex topologies of varying elements and aligns the computational model with the physical result.



Figure 11: Basic tensioned-membrane type: saddle, conical, and ridge-valley.

Reflecting upon the framework for a behavior-based design process mentioned previously, this project follows that path of cyclical development. Starting initially with studies in simple cylindrical components, the research developed iteratively both computationally and physically to evolve into a strategy for a hyper-toroidal element (Fig 12). The principle element is comprised of multiple interconnected cylindrical elements. In that sense, this utilizes a basic membrane type, the conical form, but pushes the global topology by interconnecting multiple conical elements.

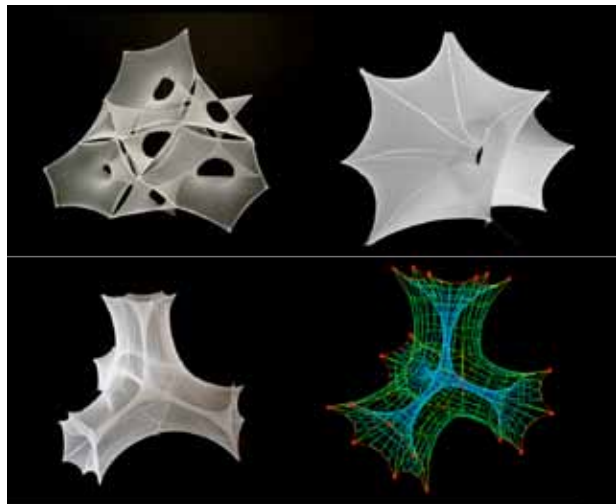


Figure 12: Iterative topology, material and computational development. An array of simple cylindrical cells is evolved into a single hyper-toroidal cell.

As a larger system, the hyper-toroidal cell is integrated into a complex mesh network (Fig 13). While tension travels within and across the cells through the various edge

conditions, by point load or edge continuity, the force quickly dissipates as surfaces sits further from the outer boundary anchoring conditions. With the inclusion of the tensioned open mesh, point loads can be introduced throughout the system. The result produces a fully tensioned prototype of a highly complex nature comparable to the initial simulation (Fig 14).



Figure 13: Hyper-Toroidal Integrated Topologies, Boyan Mihaylov, Viktoriya Nicolova, Institute for Computational Design (Sean Ahlquist, Achim Menges) University of Stuttgart, 2011. Complex tensioned surface topologies are integrated with a tensioned open mesh to strategize the distribution of tension force and positioning of geometry.

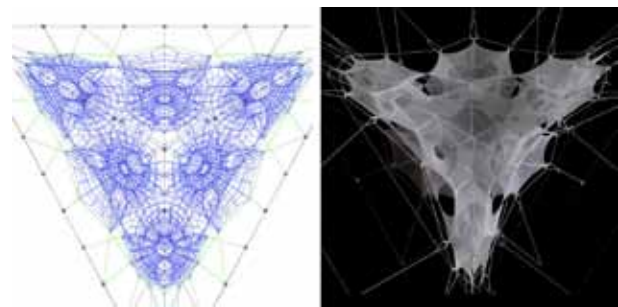


Figure 14: Comparison of computational model and physical prototype.

CONCLUSION

While computational form-finding is a valuable tool to understand the relationship between form, force and material, it has often been engaged as an abstracted tool for production solely of geometry. Its value lies within an approach that seeks to understand and simulate the whole of an architectural system, at least of its material nature. The study of the interrelation of textile composition and form performance demands a linkage between the computational

design simulation, the materialization process and resulting form dynamics. In comparison to utilizing engineering-oriented tools, a design process based-upon the use of more efficient and abstract algorithms needs informing to register and translate necessary material properties. Such is a shift process where computational behavior and material behavior are iteratively informed through cyclical processes which make precise the computational process and the resulting material system.

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Formation and Polyvalence: The Self-Organisation of Architectural Matter

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ABSTRACT

Formative design processes of self-organisation can increase the effectiveness of architectural matter's polyvalency by incorporating numerous design criteria within a networked negotiative process. By advocating for an increase in the polyvalence of architectural matter, the paper argues for more complexity within the architectural product; achievable through non-linear processes of formation. Formative processes in biology serve as a conceptual reference that informs a design research into non-linear agent based topological processes of formation. BodySwarm; the algorithmic methodology presented, offers utility in developing affective matter-relations within an architectural design methodology.

Keywords

Formation, polyvalence, matter, organisation, non-linear, algorithm, self-organisation, design, agent, topology, behaviour.

INTRODUCTION

organising matter

How might one characterise the role of the architect? Notwithstanding an architect's ambitions on any particular project, what would be considered their primary task? Architects undertake numerous roles and responsibilities, while working on a wide range of projects. In *The Ten Books of Architecture*, Vitruvius identified typologies ranging from fortifications to public buildings and private houses. More interesting was Vitruvius' description of what education an architect should obtain. Vitruvius' advocacy that the architect must acquire knowledge in a diverse number of fields suggests that he believed the architect's methodology incorporated this knowledge within the negotiated considerations undertaken during architectural design, thereby embedding a plurality of intent within the architectural product.[27]

In *Notes on the Synthesis of Form*, Christopher Alexander describes the vast number of inter-related design constraints architects creatively manage during the design process and highlighted the complex series of relations these involve.[1] Accepting that such a list of design constraints and desires exists leads one to conclude that these parameters must become essentially embedded within an architectural solution (even if invisibly) which implies that the architectural outcome is in fact a polyvalent¹ organisation of matter (as the architectural product contains multiple functions). An architect's success could therefore be attributed to how effectively they have embedded their design intent within this architectural matter. Alexander proposes that this success is largely based on how well the formal resolution of the project is intrinsic to the diagram of its design criteria - what he describes as a "constructive" diagram. Strangely the process he advocates results in an assemblage of manageably negotiated components rather than a qualitatively negotiated whole.[2]

Clearly the polyvalency of matter in architecture is not a new phenomena, yet contemporary developments in material and fabrication technologies allow for vast improvements in design control. Material fabrication processes operate at increasingly higher levels of resolution and some methods can even create differentiated material assemblages during one fabrication process such as polyjet 3d printers manufactured by Objet.² Similarly, computation has allowed innovative modes of conceptualising and solving architectural design problems to be developed through the writing of custom algorithms within the design process. Both of these factors contribute to the architects increasing abilities to specify near-atomic scaled distributions of matter in order to arrive at more specific larger scale architectural solutions.

Polyvalence implies that numerous designed affects with multiple desirable attributes may co-exist intrinsically within the design. In designing a more affective polyvalent organisation of matter as architecture, the domain of design must incorporate more negotiated matter relations that

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operate within an extended computational process of formation. This paper investigates non-linear topological processes of formation that are developed as self-organisational systems within algorithmic design processes. Such methodologies emphasise the organisation of matter to be the primary concern of the architect, and thus attempt to begin to answer the question of how one embeds design intent within matter.

POLYVALENCE

Embedded architectural intent

The analytical practice architects make of precedent studies into historical projects involves the extraction of the intent and affects from a precedent's built matter. Some of the relationships within this matter remain apparent while others are practically invisible. The spatial organisation models offered by architects such as Gerrit Rietveld, Le Corbusier or Adolf Loos are clearly different, identifiable and controlled through their organisation of matter. Loos' Raumplan offers a very different model when compared to Le Corbusier's Plan Libre.³ Their spatial orders remain clearly visible within the architectural artefact, however the emotive desires the architects had for these spaces, or specific pragmatic details requested by a client remain more ambiguous as they do not contribute to the architects' genotypical design methodologies in noticeable ways. It would be difficult to ascertain the architects' emotive intents for a particular space unless they have historically mentioned these specifically, yet it is certain that embedded within any design proposal lies numerous design criteria; pragmatic, aspirational and whimsical. An evaluation of the effectiveness to which these have informed a design outcome necessarily must include the appropriateness of the media and scale of material order in which the building proposal was realised. Scale of affect is a necessary design consideration and constraint. For example, a breathable water-proof material scaled up thousands of times would be too porous to perform as a waterproof building envelope, while a spatial organisation operates at a more human scale (yet not necessarily anthropocentric) and does not require micro-management. Scale designates the effectiveness of matter's agency, and architectural affects seem to be operating at numerous scales - from micro material scales through to larger scales of spatial organisation and perception.

Polyvalent tectonics

A number of advancements in architectural design and discourse may be attributed to the development of organisational and material developments. Frank Lloyd Wright's seminal projects were spatially charged from his strategic employment of structural cantilevers made possible through the use of the relatively new technologies of structural steel and reinforced concrete. Similarly, Mies Van der Rohe's investigations into transparency were afforded by glazing and steel technological achievements. The use of Gaussian curvature to generate the geometry for

Eladio Dieste's vault structures also shows a methodological invention that achieved similar innovation through its mathematical organisation of traditionally available materials.[12] New algorithmic methods for conceptualising and fabricating material organisations offer similar opportunities for inventiveness today.

Non-linear processes of formation and additive manufacturing with variable material-placement fabrication technologies offers a departure away from Alberti's emphasis on proportions, or Corbusier's Maison Domíno architectural system, allowing the domain of material organisation to suggest a multi-faceted design response that privileges the direct design of material placement. The emphasis shifts to a focus on emergent wholes that do not concern themselves with the assembly, expression or proportion of parts but rather with new opportunities in the formal, spatial and material affects of architectural design. This in turn, advocates the polyvalency of the material product. Polyvalency here, implies the intrinsic nature of numerous designed affects that provide for multiple desirable attributes to co-exist within the material product. A biological example of this is found in the Thorny Devil lizard; the geometry of its spiky skin facilitates capillary action in order to draw water from the damp desert soil below its feet up along its body into its mouth.[11] The geometrical organisation produces an affect of water irrigation, in addition to a spiky protection from predators while the colour patterning of this same skin also provides camouflage. Thus the Thorny Devil's skin may be seen to manage three primary roles whilst maintaining a coherent and differentiated aesthetic. In designing a polyvalent organisation of matter as architecture the domain of design is extended beyond current modes of conception and production in order to incorporate more negotiated matter relations that do not assume the need to maintain traditional modes of architectural signification or syntax. Modernist tectonic hierarchies of column, slab and wall with their fixed relationships, scales and *modus operandi* seem ineffective and antiquated in the world of contemporary science and technology where most organisations of matter just seem to do a whole lot more.

Desiring Complexity

A call for architecture to be consciously designed as a polyvalent organisation of matter advertently demands that architecture is designed with more complexity than it has been in the past. Complexity becomes a mandate for affective relations. The word complexity carries many meanings. Richard Dawkins narrows the definition of complexity to describe something as complex if it consists of numerous heterogeneous parts whose inter-relations perform useful functions proficiently without there being a simple explanation for how these parts formed into their associated relationship and little chance that they could have done so randomly.[4] With Dawkins' description of complexity, there are clear parallels between an architectural design agenda to create inventive useful things and formative processes that develop complex organisations. Edward Lorenz offers two other suitable

definitions of complexity. Lorenz suggests the word complexity describes only those organisations produced through sensitive dependence⁴ or that appear visually to require a lengthy and complicated series of instructions to create.[9] Dawkins and Lorenz are both arguing for a complexity derived from non-linear processes of formation, produced through relationships between physical forces and matter. Robert Venturi's seminal work *Complexity and Contradiction in Architecture* offered a contrasting view of complexity to that of Dawkins and Lorenz, and it is important to clarify three differences between Venturi's view and that of complex polyvalency argued for in this paper.

Venturi's "double-functioning" concept described how numerous features are resolved within baroque architecture through versatile architectural elements. (Eg. A Lintel becomes column which then becomes a skirting, etc). [24] Versatility should not be confused with polyvalence, as the former identifies the continuity of an element, while the latter is achieved intrinsically, only through the organisation of a whole that does not celebrate individual elements no matter how versatile they may be.

Venturi also argued for "partial-functioning" parts - what he referred to as "inflected elements". [25] Opposite to the double-functioning role, inflected parts were deliberately local, and were utilised to unify the whole of a building by creating a continuity through its diverse series of parts. Venturi's desire for both order and diversity can be embodied within a discourse of scientific complexity, however the science of complexity theory has no emphasis on discrete parts. Rather, wholes develop both continuity and diversity intrinsically within a process of formation that can arrive at singularities - thus then creating differentiated parts within a larger heterogeneous field. In this sense rather than parts forming a whole, parts are created from within a unified heterogeneous whole.

The two previously mentioned strategies were part of Venturi's response to an awareness of several conflicting design criteria within architecture. Venturi argued that numerous design criteria created contradictions within the architectural product (such as an ideal for an interior plan contradicting a modified exterior due to adaptations necessary for the site context). These contradictions he considered necessary and desirable.[26] Conflict is indeed a creative force in which interesting architectural solutions arise, however Venturi's historical examples of "contradictions" are mostly superimpositions; while they do offer tension, the solution is a visual hybrid, of two opposites. In a non-linear formative design approach, contradiction is re-envisioned as an input of conflicting desires - that after negotiation produce a qualitative and negotiated response whilst maintaining the tensions and conflicts that Venturi valued as something perceivable and visually affective.

FORMATION

Generative techniques of matter function

Formative processes were utilised by Antonio Gaudi and Frei Otto in the conceptual design of architecture via physical modelling processes. Their models allowed negotiated design criteria to be embedded within their working methodologies. In Gaudi's catenary models, space and form is negotiated through gravity and tension constraints that operate within a network of suspended chains. The network organisation of chains defined by their local connections, varied lengths and the strategic placement of weights; allowed Gaudi to design and calibrate a range of building proposals. By inverting these models, Gaudi managed to achieve innovative compression structures.[7] These material models thus embodied design constraints that allowed for a negotiative process in order to arise at an architectural solution. The constraints were intrinsic to the design methodology, and the architect's role revolved around the orchestration of designed relationships rather than on any explicit geometric outcome. Unlike a representational architectural model created to communicate a final proposal to a client, these models may be understood as operative design models, where formation involves constraints intrinsic to the material organisation itself. Design intent is embodied within matter in such a process. Reminiscent of Deleuze and Guattari's idea of "matter-functions" [5] these models may be understood as attempts at "abstract machines" where one can imagine design outputs may arise from a design "set up" that contains no a-priori explicit constructs but rather a series of established relationships. Due to the physical nature of these models, they may also be understood as not abstract enough, thus falling under the same category Deleuze and Guattari's designate to Noam Chomsky's generative grammar.[6] Where Chomsky's work does not escape syntax, Gaudi's models do not escape the language of their materials. This limitation ensured that the design problem remained dialectical (structure vs space) and abstract. The physicality of the model limits its ability to incorporate numerous additional design criteria or represent the behaviour of actual building materials at one to one scale (as the models utilise other materials at smaller scales). The constraints that allowed a negotiative process to take place are also the constraints that prohibit additional design goals to be incorporated into the model. Only design goals that may be played out through the desires of gravity and tension may be incorporated. Despite the inventiveness of Gaudi's design process, it is doubtful that the catenary models could allow for environmental or temporal considerations. With algorithmic methods of self-organisation, more advanced formative processes may now be achieved that are not limited in the number of design criteria or the material formations in which they are realised.⁵ What is the significance of this embedment of intent within form?



AirBaltic Terminal Proposal, Riga Airport (Kokkugia and BuroHappold, 2010)

This paper investigates topological transformative processes that may be driven by self-organisational logics algorithmically. The former can deal with spatial and formal configuration while the latter ensures that such a methodology incorporates numerous design criteria within a negotiative non-linear process of becoming.

Developmental biology: topological organisations of matter

Both plant and animal processes of formation contain mathematical and topological principles in addition to the genetic and chemical instructions underlying their myriad of procedures. While chemical and genetic processes are also relevant to architectural design, this paper emphasises the spatial aspects of formation, and is thus largely focused on the mathematical and topological processes of formation and their relationship to internal and external physical forces.

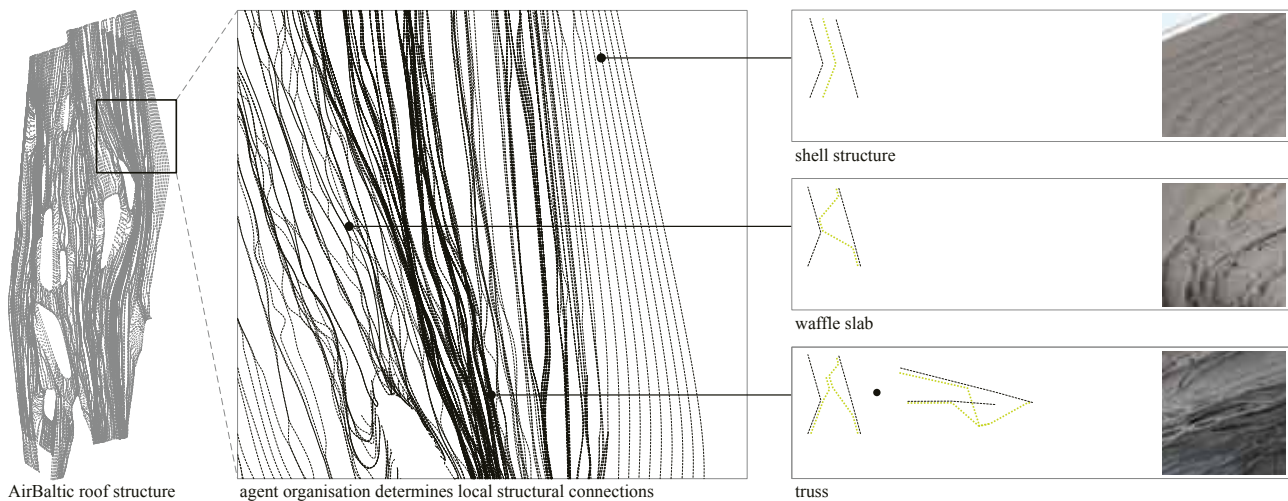
Formative processes of materialisation naturally involve physical forces simply due to the fact that the materialisation takes place in the physical world and is therefore subject to real world physics. Architectural formation can arise from real world processes of material self-organisation, or through simulated computational models that are then fabricated as artefacts of the simulation (As discussed in relation to Gaudi's catenary models, the author privileges the algorithmic models over Gaudi's analogue models due to their ability to allow for a potential infinite number of criteria to be placed into a networked negotiation). In both cases, the organisational matrix of matter will inevitably be placed into architectural scenarios where it must negotiate and resist real world forces. For this reason, formation can benefit from some understanding of physics, within a creative context. D'arcy Thompson astutely highlighted how material processes were involved in the creation and growth of living organisms, and therefore subject to natural physical laws such as force.[20] Thompson's insights don't adequately describe the physical aspects of developmental biology sufficiently to be of use for architectural design,

however a number of other scientists have progressed this work.

Lewis Wolpert provides a clear overview of the development of the embryo in a number of well-studied animal species in his book *Principles of Development*. Wolpert outlines the role of chemical processes that drive cell division and differentiation within embryogenesis and how this leads to topological transformations in time.[30] Events such as gastrulation within the formation of an embryo involve topological modifications of surface in order to initiate the generation of elements such as the gut. René Thom has attempted to identify such events as "catastrophes", where he describes the underlying mathematical principles that can allow such unpredictable topological events to occur [19], emphasising their common occurrence throughout natural systems.

These processes of development are undertaken through a series of continuous events. Wolpert states that embryogenesis is a "generative" process, not a "descriptive" because a vertebrates DNA does not operate as a set of architectural drawings but rather as a series of encoded instructions throughout the formation of the embryo. He aptly points out that it is far easier to work this way, providing the analogy of origami and illustrating how it is far easier to explain how to make an origami object via a set of instructions compared to describing its end result. [29] Architectural design involves far more complexities than origami so it would be reasonable to assume that a generative process would be easier to manage than a descriptive one also.

Johann Wolfgang Von Goethe and Stuart Pivar have both undertaken arguments in support of event-driven development that although not as scientifically comprehensive as Wolpert's description, serve as a good illustration. Stuart Pivar's *On the origin of form: Evolution by self-organisation* graphically proposes a embryogenetic process that operates through a series of recursive topological transformations that describe formation of the embryo from macro form all the way down to surface



articulations such as finger nails, fur and feathers.[13] These operations demonstrate a repeatable series of formal procedures that work throughout time at various scales. Similarly, Goethe's *Metamorphosis of Plants* was written in the eighteenth century and therefore preceded a possible genetical description of growth, yet Goethe categorically outlines the formation of varying attributes within plant growth that not only follow observable behaviours sequentially in time but that produce very different features at various points from the same formative base. [8] Both Goethe and Pivar's observations describe an event based set of topological transformations in time that operate through a combination of internal relationships and their negotiations with physical forces; offering a useful concept for a design methodology whose negotiations could be driven by a self-organisational system.

Formative processes of self-organisation

Formation typically describes a process that undergoes a series of negotiations in order to arrive at a solution, where matter is organised into a specific set of spatial relationships. The chaotic property of even simple spatial negotiations was understood by Henri Poincaré in his study of the gravitational forces of orbiting planets; and described in his 3-Body problem as early as 1889. This mathematical non-linearity that impacted the study of celestial mechanics and dynamics theory describes one of the core principles of a self-organisational system; a system which comprises of three or more elements in a networked series of relationships may produce unpredictable behaviour. [4]

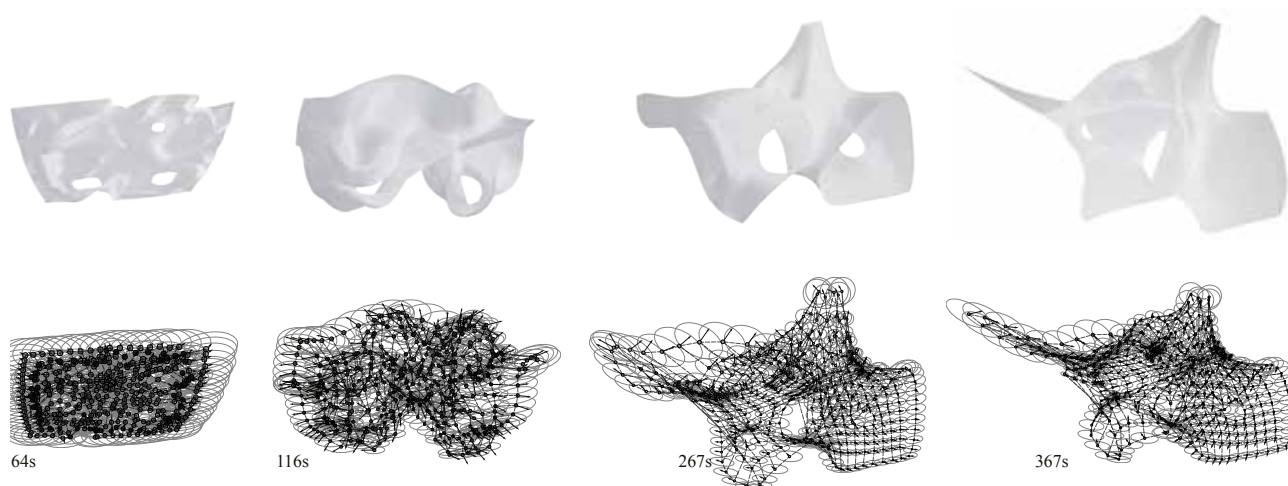
The networked relationships of orbiting planets describes a non-linear dynamics system that after a period of time may exhibit emergent properties such as dynamic stability (where the overall configuration of planets forms a pattern of behaviour that may be described as characteristic of the system), or come to rest in a particular configuration where most movement has been mitigated (a near-equilibrium condition). Both these scenarios may be viewed as negotiated solutions to the overall system. The systemic process arrives at an emergent outcome through the interactions of its constituent parts alone. It is interesting

to highlight that while such methods of interaction are quantitative, the term emergence here infers a qualitative and subjective description of a visually recognised spatial order that arises within such a system. In this sense the architectural merit of such a process lies in both the pragmatic solution and the design desire for an emergent affect that is intrinsic to this solution.

More elaborate task orientated behaviours are evident in the self-organisational systems of ants or termites where the contributing individuals collectively navigate, congregate, or build emergent organisations through their local interactions alone. Scientists such as Guy Theraulaz and Eric Bonabeau have demonstrated the algorithmic nature of such self-organisational systems and how these may be simulated computationally.[3] Rather than mimicking such natural behaviours, developing self-organisational models as design methodologies allows the designer to define specific agencies relevant to an architectural design agenda. The specific autonomy of individual agents⁶ with uniquely specified design tasks enables goal-orientated collective behaviours to emerge within a designed system. Assigning varying and multiple desires to each autonomous agent within a network organisation facilitates the incorporation of multiple design criteria in order to produce a negotiated and emergent outcome. Such outcomes embody design intent within architectural matter.

NON-LINEAR DESIGN CASE STUDIES

Agent-based negotiations: performance and design intent
Kokkugia's⁷ long-term research into self-organisational processes has involved the development of agent-based design methodologies where design intent is encoded within autonomous decision-making algorithmic entities. These custom written software codes are event-driven, where discrete individuals behave according to their assigned desires and constraints in response to local events. The collective behaviour exhibited within thousands of encoded entities has provided insights into the generation of emergent organisations of matter. The inter-relational



bodyTopologic event driven formation documented in seconds following code execution

code structure is custom written for each specific design problem yet remains open to additional constraints that may be added as required. This systemic openness has enabled different design negotiations to be accommodated in a number of different projects.

In collaboration with the engineering practice Buro Happold, the AirBaltic Terminal proposal for Riga Airport incorporates Kokkugia's agent based code with Buro Happold's structural analysis software. A swarm based fibrous network was developed that consisted of agents representing nodes on a series of parallel strands in order to define the airport's roof structure. These agents engaged in a dynamic repositioning with their connections to adjacent nodes being created and broken in response to local structural performance. The concrete roof structure developed an architectural and structural solution through local behaviours, with each node having no overall knowledge of the extent or profile of the roof. Rather each agent behaved in its own best interests, thus allowing an overall solution to emerge from the collective organisation. Despite no predetermined structural system being defined in the initial setup, the resulting roof structure appears to shift between a number of known structural systems within its local organisation; including shell, waffle and truss configurations. The Air Baltic project demonstrates the incorporation of the performative criteria of structure within a non-linear algorithmic design methodology that has other spatial and formal design intent embedded within its rule set. The structural solution is not optimal, yet the process ensured a structural integrity was intrinsic to the architectural intent which prioritised spatial and ornamental design concerns. The algorithm undertook a spatiotemporal negotiation.

bodySwarm: a versatile design model

Historically Kokkugia's investigations into design agency have seeded design intent within micro-scale relations that negotiate as point, line or curve conditions in three-

dimensional space to arise at complex formations that define geometry for a number of projects. More recently, this work has been extended to assigning agency to surface in a new methodology called *bodySwarm*. By operating on an a-priori surface whose nodes are defined by a swarm of autonomous agents, *bodySwarm* is able to undergo intensive topological formation through controllable and manageable self-organisation that is not bound to its starting topology or the quantity and configuration of constituent agents. The agent nodes in *bodySwarm* are connected to each other with a series of springs that imbue the system with a controlled abstract material sensibility. The agent based behaviours develop dynamic stability or near-equilibrium conditions to resolve their negotiated design constraints. *bodySwarm* is an attempt at developing a re-usable design model; the contemporary equivalent of Le Corbusier's *Maison Citrohan* studies.[17] However, rather than focusing on building typology, *bodySwarm* attempts to define a versatile design methodology where multiple design criteria can be seeded into a process of formation that may be customised for the design of a broad range of quantitatively and qualitatively differentiated projects.

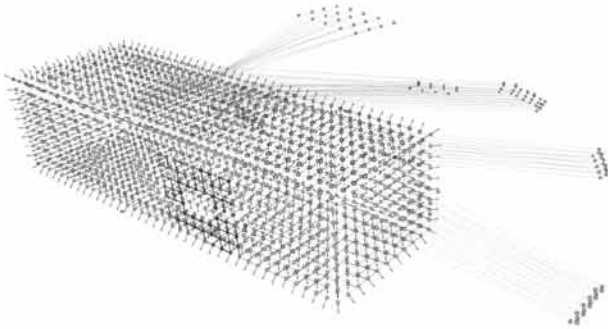
The *bodySwarm* algorithm operates through a number of key behavioural logics including;

Autonomous agent-based decision making

- Swarm behaviours: cohesion, separation, alignment, wander. (Similar in concept to Craig Reynolds' BOIDS [15])
- Agent types and related task assignments
- Spring networks: The physics of elasticity, agents are free to make and break connections of varying elasticity

Surface topology

- Manifold (bridge) connections may be made and broken.
- Stitching: Edges may be stitched together modifying topology also.
- Tearing: Creating holes within surface arrangements.



Busan Opera House self-organisational design process: design template and final result (Kokkugia 2011)

Surface properties

- Allow the topological organisation to respond to local surface properties such as tension/relaxation, surface type, orientation and curvature. This information is transmitted through algorithmic rules similar to those of Cellular Automata.⁸
- Subdivision: size and geometry of surface mesh faces defined by numbers and density of agent nodes.

Physical constraints

- Fixed: points, surfaces, boundaries.
- Attraction and repulsion to external stimuli.

These principles form the basis of a tightly inter-woven set of event-driven behaviours that execute locally, based on associative relations to adjacent stimuli. While the rules remain constant, agent behaviours are locally differentiated due to their local differences in scenario. Acting on a simple initial surface the simulation develops topological and volumetric transformations in order to define spaces, their networked (or topological) arrangement, and the formal character of the surface itself.

This essentially bottom up process may be utilised with a varying degree of specificity in starting configurations and constraints. In order to demonstrate this, two very different strategies for implementing bodySwarm are outlined through the Busan Opera project and BodyTopologic research project. BodyTopologic investigates an extremely bottom-up simulation where little can be perceived as top-down in the algorithmic setup, whilst the Busan project has some deliberate top down constraints defined in the initial setup that aid in the development of the design proposal.

BodyTopologic: self-organised topological formation

The research project demonstrates a formative process of self-organisation. A series of complex topological surfaces emerge from the local interaction of agent based surface nodes and their event triggered behaviours. BodyTopologic proposes formation as a series of local and inter-related

events, that allow for a range of surface conditions to arise and trigger further change. Inspired by the graphic topological transformations outlined in Stuart Pivar's *On the origin of form: Evolution by self-organisation* [13], in BodyTopologic, complex behavioural relations deterministically mine topological events. Rather than work from a mathematical description of topology such as those formulated by Rene Thom that explain these topological events as complete mathematical catastrophes, BodyTopologic recognises Wolpert's acknowledgement that complex organisations are far easier to understand as a generative set of instructions compared to any attempt to describe their results descriptively.[29] The mathematical description of the resulting surfaces is not as useful here as the matter-relations that define the surface formative process in time, as these provide an operative construct that is controllable through the alteration of the coded network relationships. The outcome of a BodyTopologic simulation is difficult to predict, and must be run many times in order to gain an intuition for the algorithmic behaviour and character of the methodology. Small changes in relational rules can cause radical shifts in the resulting topological configurations. While the simulations clearly solve their own internal relational discrepancies in order to arrive at a negotiated solution there is a clear lack of external constraints that would be required for a design methodology.

Busan Opera House: design methodology

The Busan Opera House competition incorporated design constraints into the initial setup defined in a customised variation of the bodySwarm methodology. A number of the event-driven behaviours available in the BodyTopologic research project were coded into the initial setup surface (by assigning numbers and positions of different agent types that have different encoded behaviours). Where BodyTopologic triggered all behaviours through local events (identified spatiotemporally), Busan employs the embedment of 'behavioural triggers' within the setup surface, thereby utilising a design template that initiates a number of the same behaviours utilised in BodyTopologic



Busan Opera House proposal (Kokkugia 2011)

at the beginning of the simulation. Additional behaviours are also triggered locally through events in time. In this sense, the initial setup surface in Busan acts as both the DNA (behavioural instructions) and a design pattern (spatial template as done in fashion design) for a recipe of formation.

Through the employment of the initial setup surface in Busan, very tight control is achievable in both the initial constraints and topological output, despite the unpredictable nature of the non-linear process of formation. Whilst outcomes are not known prior to the execution of the simulation, iterative changes to the initial setup file can allow for incremental improvements to be made to subsequent runs of the simulation. The Opera House design involved the development and execution of over 3000 simulation runs that required varying degrees of amendment to either the initial setup surface or the coded behaviours defined in the algorithm. The initial setup file and the coded behaviours, placed the self-organisational system in a scenario in which it had to solve its relations in order to arise at a formative design proposal. The process of formation is intrinsic to the formed result.

A series of further detailed design refinements were undertaken to resolve planning and formal character issues, by re-simulating parts of the project. A defined threshold

was specified that ensured a gradient range of influence could allow some parts of the project to remain fixed while other areas were able to continue to compute their negotiative relations. In this sense the Busan methodology hybridised the non-linear self-organisational process with repeated subjective designer input, allowing for both pragmatic and design criteria to be honed throughout the design process.

Kokkugia's research into generative design methodologies is concerned not only with solving the practical resolution of a design problem, but also the generation of a unique formal character for each project which arises out of its process of becoming. Design intent is seeded within a process of formation. Multiple design criteria are placed into negotiation within a formative process resulting in a proposed organisation of architectural matter. This embedment of multiple design criteria within the formative process aspires to produce a more affective polyvalent matter-organisation. The resolution which this architectural matter is designed at, would inevitably determine how affective its designed polyvalence would be. As such bodySwarm is being tested at numerous scales for various design applications, it is hoped that it will offer another means to define a highly articulated matter whose complexity gives architecture additional polyvalence and character.



ACKNOWLEDGMENTS

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NOTES

- 1 The New Oxford American Dictionary offers a definition of polyvalent as “having many different functions, forms, or facets” [22]
- 2 Objet’s 260 Connex 3d printer can include up to 14 different materials within a single printed part with a resolution as accurate as 16microns in dimension. [23]
- 3 The 010 publication “Raumplan versus Plan Libre” provides a good comparison of Adolf Loos and Le Corbusier’s architectural methods and design results.[16]
- 4 Lorenz argues that a definition for the mathematics of chaos requires sensitive dependence - where small changes in initial input relationships can cause unpredictable strange changes in the output of a system. [9]
- 5 Non-linear algorithms such as agent based swarm systems define a networked series of relationships that need not maintain an a priori hierarchy of relations, thus

allowing multiple often conflicting design criteria to negotiate in a flexible and open manner. This is difficult to achieve in parametric or associative modeling softwares such as Catia or Grasshopper due to the requirement to define hierarchies of associative relationships. Conversely, custom written algorithms may assign equal or differentiated influence to various parts of the code as desired. See [18].

- 6 An agent here refers to an autonomous individual entity capable of making its own decisions amongst a larger population of individuals. In Kokkugia’s work, this typically refers to a scripted individual who has rules relegating it’s behavior relating to Kokkugia’s design intent. In agent based systems the emphasis is on the collective behavior indirectly controlled from many agents individual decisions.
- 7 Kokkugia is a design practice based in London and New York run by co-founding directors Roland Snooks and Robert Stuart-Smith.
- 8 Cellular Automata (CA) are a class of computational algorithms that define the state of discrete elements in relation to their neighbor’s states. CA have been developed in multiple dimensions, with varying numbers of states, and ranges in neighborhood sizes. A number of rules specify how each element’s state will be adjusted based on the state of its neighbors. Cellular Automata was first developed by John Von Neumann and have been further developed by scientists such as John Conway, Chris Langton, and Steven Wolfram.[28]

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Textile Qualities: Parametric Design, Simulation and Fabrication Based on New Composite Materials

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ABSTRACT

In this paper, we describe the use of new composite materials with the ultimate aim to build new structures of complex geometry in a simplified way. Our intention is researching digital design influenced by innovative software applications and potentials for new production processes in architecture. Through prototyping, ideas can be tested, regarding the effects of material behavior, which are beyond physical representation.

Keywords

Parametric design, composite material, fiber concrete, molding techniques, simulation, fabrication

SCRIPT BASED DESIGN RESEARCH IN CONTEMPORARY TEACHING PRACTICE

The institute for experimental architecture.hochbau at the University of Innsbruck/Austria has set its focus on script based and parametric design research within the last several years, aiming to explore new design methods in order to advance the field of contemporary digital architectural design. [2]

During this time, several new approaches to digital design have been developed, iteratively tested, improved and applied in different architectural scales such as the urban scale, the building scale and the ergonomic scale. [1,4]



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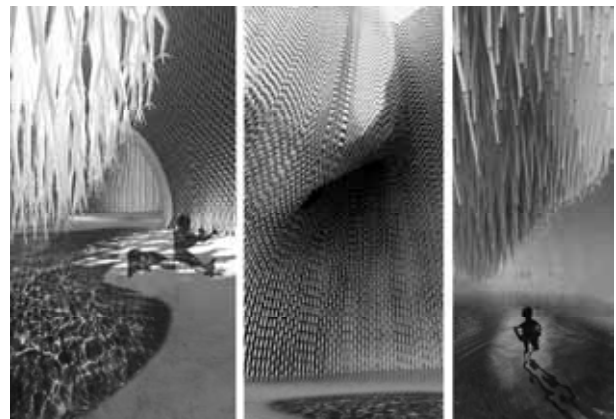
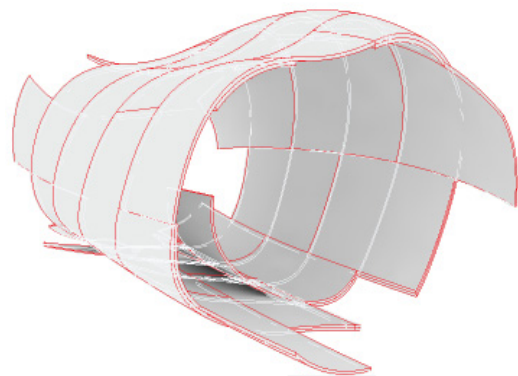


Figure 1: Script based and parametric design research; Differentiation in different scales (P. Mandler, Innsbruck University)

Another intention of our institute is to bring several domains into correlation not only by enabling a wide range of different design parameters but also by integrating different and various material and structural requirements. According to the specific knowledge of experts and engineers under a systematic mindset, forming intricate correlations and intensify relations is essential. [7]

Within the field of parametric design the separation of cognitive processes and material logics is obsolete. A new correlation between design and manufacturing can be seen as an elementary change in architectural production.



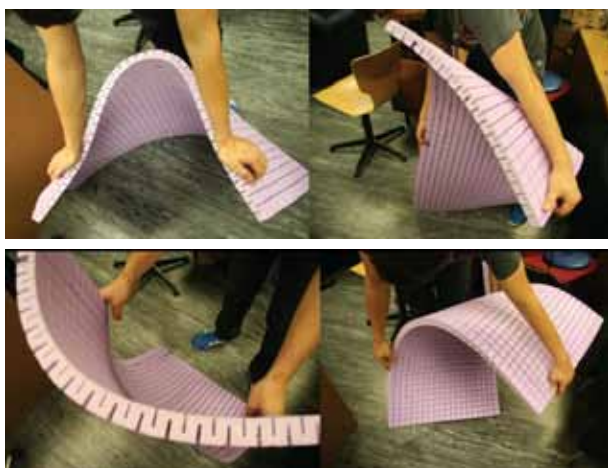
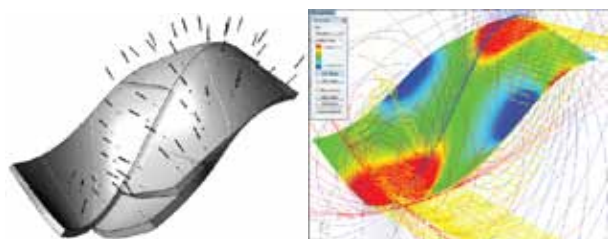


Figure 2: Correlation of design, material and manufacturing logics (F. Fender and T. Hillebrand, Innsbruck University)

EVOLUTION OF A PARAMETRIC SHAPE REPERTOIRE THROUGH SIMULATION

Technological material inventions often introduce the need to rethink design, simulation and fabrication methods in architectural design and structural engineering. New approaches and the usage of new tools and techniques of planning, developing and fabrication made possible the use of free forms and free geometries, thus leading to a widening of the architectural shape repertoire. This digital revolution entails an enormous gain in both freedom and complexity.

Experimental modeling with composite materials is extremely straightforward and convenient. There are, however, huge gaps in the work flow when it comes to CAD modeling and actual fabrication. Efficient CAD

models are not available and fabrication is only possible at modest size.

Our intent is designing processes and exploring possibilities for a later efficient fabrication process.



Figure 3: Exploring complex material behavior by a robotic test setup (Splintex, Innsbruck University)

The possibility to embed physical behavior directly in the 3D modeling environment allows interaction in real time. It is also possible to have various sorts of optimization, structural analysis and animation.

By using particle simulation software like Kangaroo – a plug in for the 3D Software Rhinoceros/ Grasshopper – it is possible to simulate physical behavior. As the simulated objects have assigned mass, position and velocity, they are able to respond to forces. In this way a wide range of interesting behaviors and a variety of non-rigid structures can be built by connecting elements.

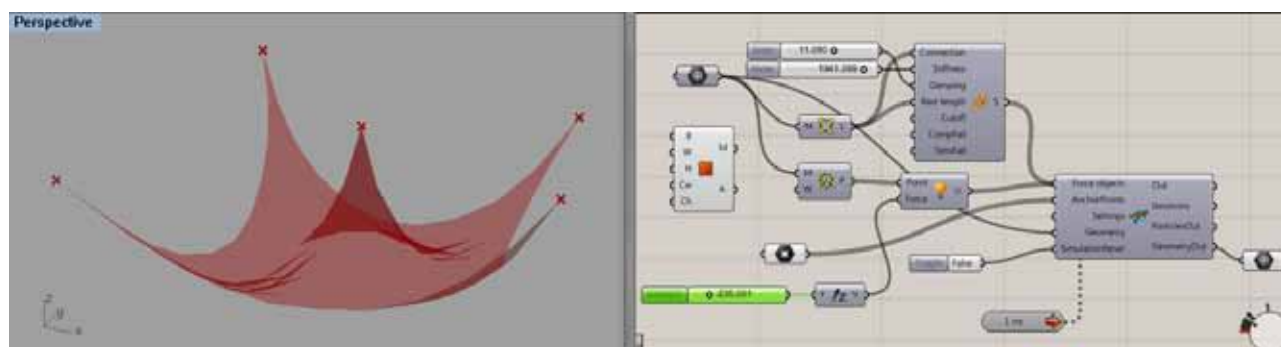


Figure 4: Simulation in Kangaroo, plug-in for 3d-modelling Software Rhinoceros / Grasshopper

Although these particles are an abstraction, it has a strong connection to our understanding of how the real world works at a fundamental level. Macroscopic properties of materials such as their behavior in bending, shear and torsion can actually be seen as emergent on a molecular level from simple interaction between pairs of particles.

Via this method we can quite accurately approximate of real physical behavior.

While they do have their limitations, one great advantage of particle systems is that they are easily understood and controlled (compared with more sophisticated continuum models). [5]

NEW COMPOSITE MATERIAL DEVELOPMENTS AND THEIR PERFORMATIVE CAPACITIES

In comparison to other material driven strategies, the composition of different components allows the imitation of natural heterogeneous material properties. Therefore, the complex structural behavior of composite materials like fiber concrete as well as the specific material conditions differs from most building materials.

Advantages of a soft and flexible state are significant. The available dimensions increase due to more flexible conditions in transportation and complex geometrical structures are achievable in a simplified way that is usable for a wide spectrum of applications in architecture and design.

Especially the technology and production processes of fiber concrete have advanced in the past decades, however short fiber reinforced panels are often unable to fulfill structural demand on site. The orientation of fibers in the panel is almost random and their non-directional distribution increase load resistance only slightly.

By improving the incorporation of layers of fibers into a concrete matrix the steel reinforcement often becomes unnecessary and the number of possible applications increases.

This allows the construction of elements that are highly stressable despite being extremely thin-walled with a high tensile strength.

While fibers are able to absorb tensile forces, concrete is known for compressive loads resistance, therefore a good composite of textile reinforcement and concrete matrix is important to achieve the maximum potential of this process.

The bonds between the fiber component and the concrete matrix are part of the key bonds that allow for the high tensile performance that can be expected, the other key is the bonds that exist between the fibers.

In the past few years research on textile reinforcement in building industries has developed quickly.

The resistance fibers like alkali-resistant glass, carbon or basalt as well as improved production methods of multi-layered textiles have made powerful reinforcements available.

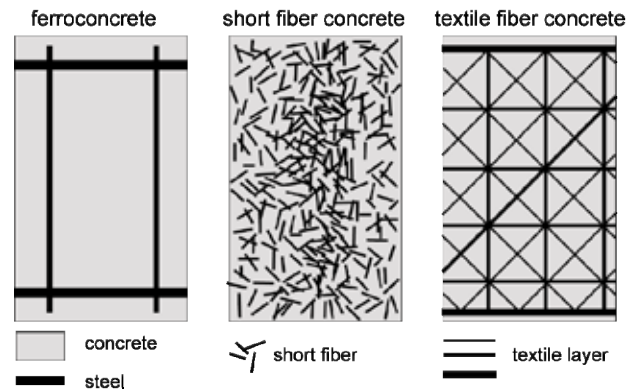


Figure 5: different reinforcement strategies of concrete

The tensile resistance exactly in areas of a component where needed as well as an economic usage of expensive reinforcement material gets nowadays possible but research and optimization possibilities are still huge and guarantee an interesting field for development in the future.

The development of fiber concrete as a new composite material combines the advantageous material properties of both concrete and technical textiles.

The heterogeneous textile structure leads to a complex structural behavior but the high load bearing capacity and the ability to deform under tensile stress is comparable to conventional reinforced concrete.

Due to different properties of material and composite, conventional structural design models from reinforced concrete construction cannot be overall/generally assigned.

Through one-axial tensile tests, the material properties of fiber concrete can be evaluated and the stress-strain curves can be described throughout 3 conditions:

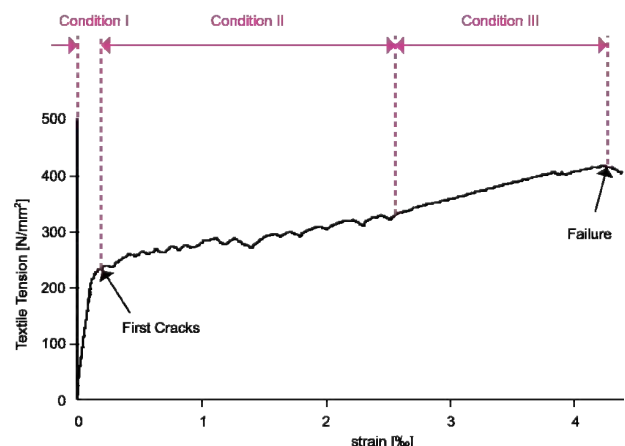


Figure 6: stress-strain curve and conditions of cracking

Condition I – crack-free:

In this phase textile reinforced concrete doesn't show cracks and behaves almost linear-elastic. The stress-strain curve is defined through the modulus of elasticity E_c of fine grained concrete.

Condition II – cracking:

In this phase multiple cracks on the component appear, the tension-level can reach a value of approximately 1.3 at the end of this phase.

Condition III – final crack pattern:

Increased tensile stress and strain in the textile lead to failure. The stress-strain curve is defined through the modulus of elasticity E_c of the fiber material.

CASE STUDIES

The following examples are student works that were developed regarding the new possibilities of parametric design and fabrication for fiber concrete during the year 2011.

CNC Sandbox

This project follows the simple idea of shaping fiber concrete panels through molds out of sand. A fresh industrially produced panel, covered on both sides by a plastic foil is positioned on the mold and can be removed after one day of pre-hardening. The sand then can be re-used for further molding.

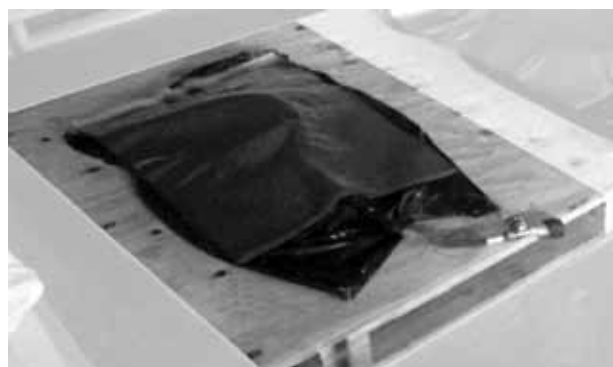
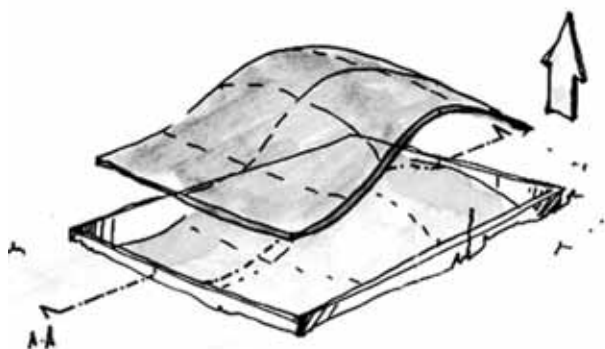


Figure 7: shaping panels through molds out of sand (W.Bechtold)

To improve the molding technique, a CNC-controlled vacuum cleaner shapes the sand based on specified data. Compared to common CNC-milling techniques with polystyrene, the material is inexpensive and 100% recyclable.

In a further step the loose sand mold is sealed by a foil and gets carefully evacuated. A very hard and stable mold is the result.

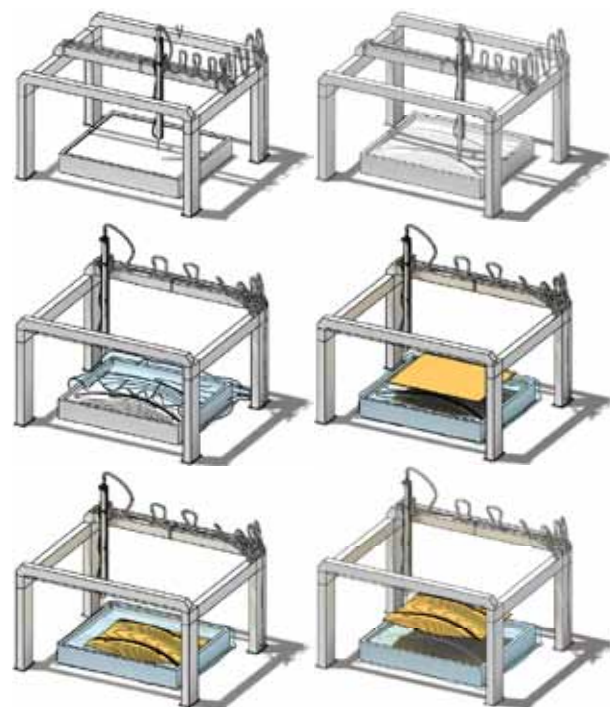


Figure 8: Steps 1 to 6; 1.freshly prepared sandbox, 2.CNC-controlled vacuum cleaner starts, 3.mold is sealed and vacuumed, 4.fresh fiber concrete panel gets positioned, 5. hardening for 24hours 6.vacuum gets dissolved and the panel can be removed.

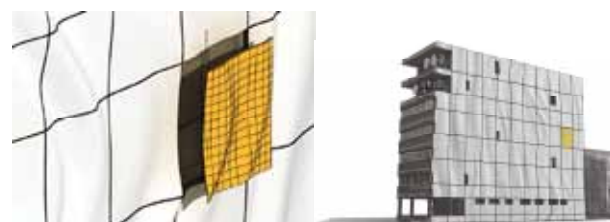


Figure 9: A customized hanging curtain façade as an example for application

L'Arc

This project is based on the analyses of free form molding techniques and the possibilities of simplifying double curved surfaces. The use of circle segments is geometrically simpler to handle, easier to fabricate and allow an approximation to complex geometries.

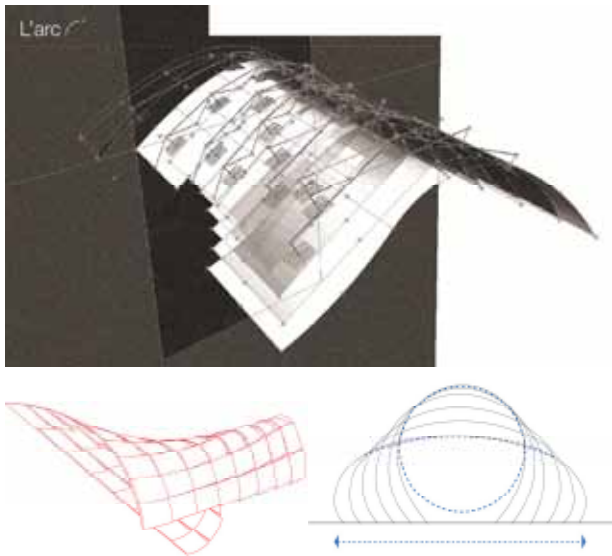


Figure 10: Circle segments are geometrically easier to handle; (C.Ganslmeier, Innsbruck University)

Through a computer script, section lines of random surfaces can be automatically generated.

By dividing these lines and then generating arcs - each consists of 3 points - an approximation to the intersection curve can be reached. The direction of the extrusion is determined by the UV direction of the surface.

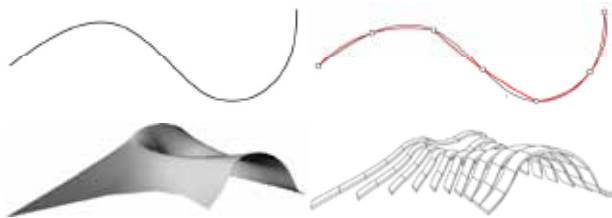


Figure 11: Principle of approximation through circle segments;

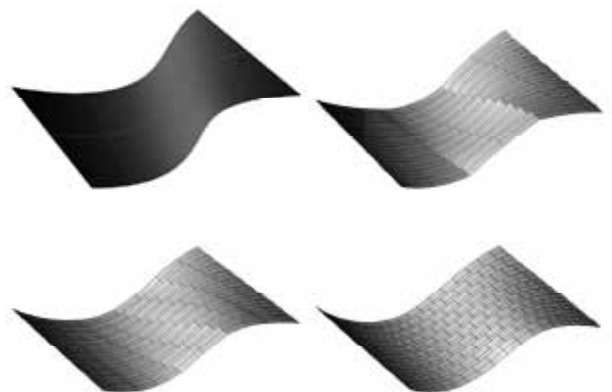


Figure 12: Dividing a surface into section lines and further approximation through segments;

Parametrically manipulation possibilities are:

Selection of base surface, number of segments in a row, number of rows, thickness of arc elements, height and number of joints of space frame and diameter of beams.

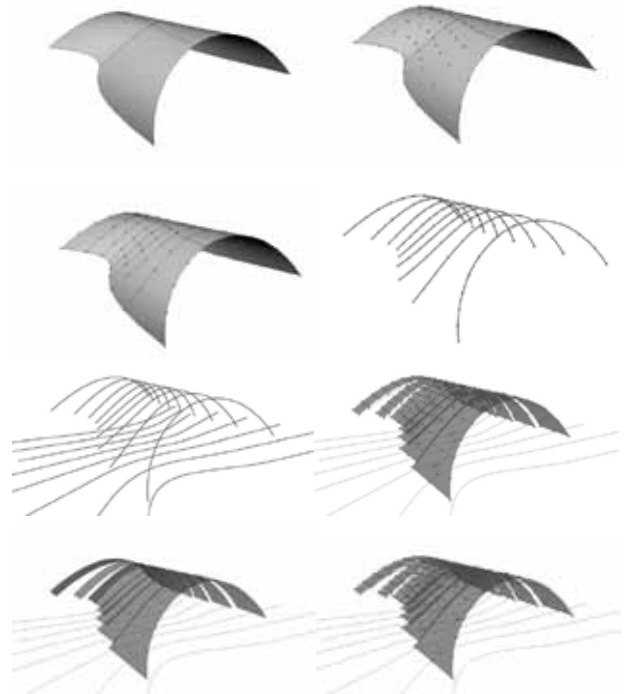


Figure 13: Functions of the design script, Steps 1 to 6; 1.random surface, 2.UV-grid, 3.connecting U-points through a Nurbs-curve, 4.interpolating points through arcs, 5. project to C plane and loft interpolated arcs, 6.generate UV grid on new surface, 7.perpendicular to point on surface, 8.combine points for space frame.

Concrete Netting

This project developed a spatial structure using fiber concrete that could be applied to multiple functions.

Its fabrication is based on a flexible formwork and the development of a free form modeling machine.

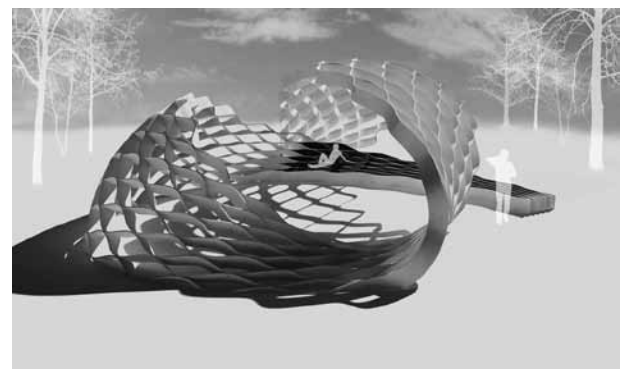




Figure 14: spatial structure using fiber concrete; (G. Racz and I. Parth, Innsbruck University)

The aesthetically distinctive characteristics of the material, its light weight as well as its free form capabilities are highly advantageous; furthermore, due to weather resistance multiple exterior assignments are possible. (e.g. urban furniture, pavilion, exhibition stand or facade elements).

An example is the design of an open-air pavilion situated in a park that invites people to sit down and relax or serves as a stage for performances.

The space between the elements could be filled through ETFE-pillows to provide a waterproof skin or through cushioning used as seating furniture. The expressive formal design should give a feeling of a high diversity of reachable shape repertoire.

Through the development of a computer-script (a parametric model that could be generally applied to free form shapes) strips are generated based on a free-form surface.

These Strips then get divided into single elements and all the necessary data for an automated production gets provided. Parameters like amount, height, width or curvature can be adjusted easily to the desired design and scale.



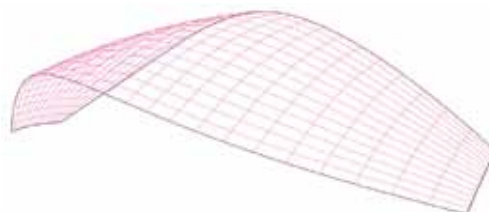
Figure 15: set of parameters;

Set 1: number of elements in x direction (9), number of elements in y direction (6), element width (0,5 m), element thickness (35mm), tangent length (0,6 m)

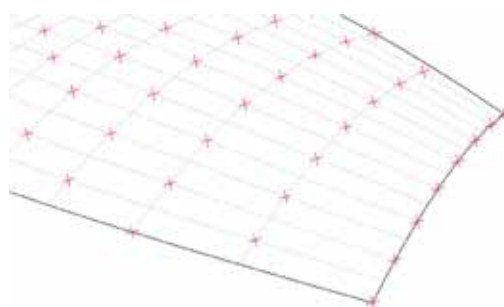
Set 2: number of elements in x direction (10), number of elements in y direction (10), element width (0,5 m), element thickness (35mm), tangent length (0,6 m)

Set 3: number of elements in x direction (10), number of elements in y direction (10), element width (0,3 m), element thickness (35mm), tangent length (0,4 m)

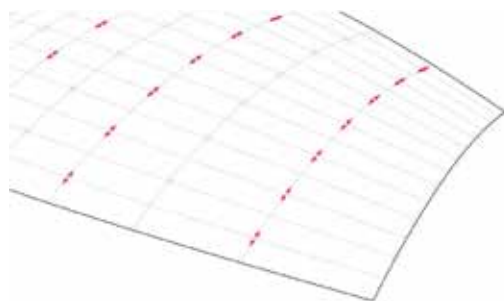
The following geometric setup describes the script step by step:



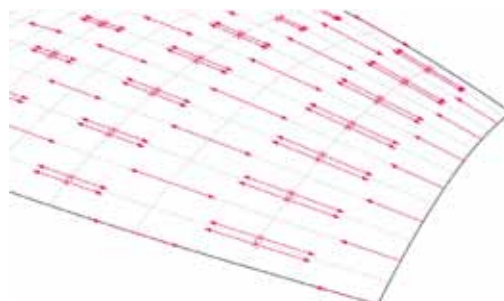
Step 1: Generation of a user-defined freeform surface; division into UV Frames; the amount of UV-Frames defines the amount of the final elements.



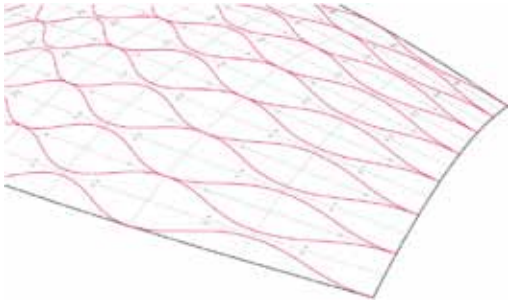
Step 2: Selection of every second UV-intersection point on the surface.



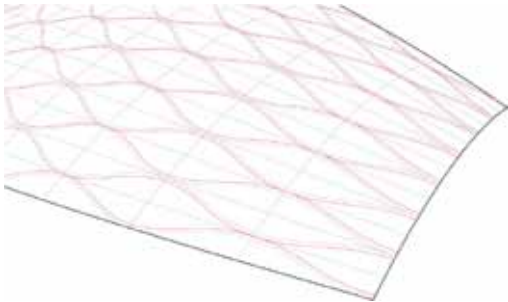
Step 3: Point offset distance in every 2nd row defines the depth of the fiber concrete material.



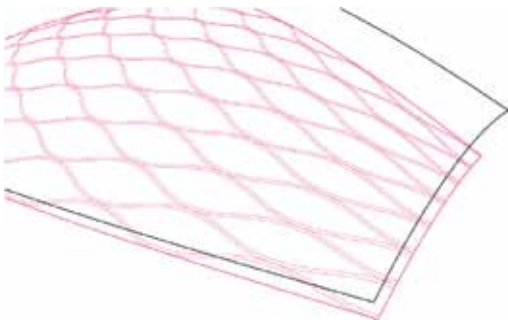
Step 4: Define tangents through the points on the surface.



Step 5: Generating Bezier-curves consisting of point and tangents.



Step 6: Creating curves parallel to existing Bezier-curves.



Step 7: All previous steps will be repeated on an offset surface. The distance between the surfaces defines the width of the elements.



Step 8: Creating surfaces of the elements through guiding curves.

By inversely arranging the fiber concrete strips in an inversely related manner, it allows a bolting/ spacer system

to be installed; providing stable and friction-locked connections.

The necessary position data is calculated and due to a flexible mold all parameter of each element can be set. A Fiber Concrete Panel is placed in the mold for hardening.

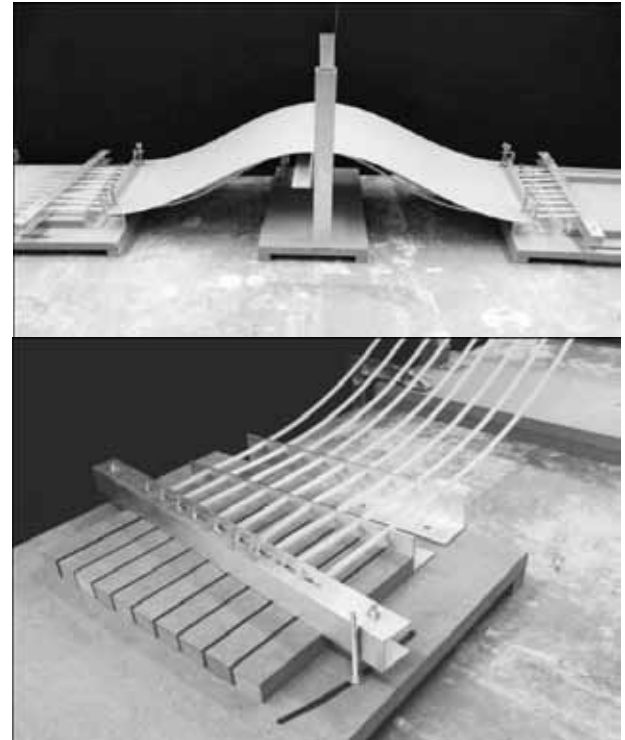


Figure 16: Prototype of the modeling for producing elements of fiber concrete;

A simplified prototype of a modeling machine proves that all the desired shapes were able to be reached. All 3 control axis are able to be precisely adjusted in space, the areas between are interpolated and little tolerance is accepted. In the first prototypes polyamide sticks were guided through 3 control axis. Because of the weight of the fresh fiber concrete panels, the desired tangential transitions couldn't be reached and marks appeared on the concrete surface. As an improvement a thin PVC-panel (an unrolled cutting pattern that was generated through the available 3D data) was added to the machine.

Higher stability and a better approximation to the desired shape had been reached.

CONCLUSION

The results of a parametric approach show the great potential for students to explore how form and textile material properties are related. The use of new automated manufacturing methods like robotics or custom made CNC machines enables a cost-effective production and freedom of spatial constructions in architecture.

To fully take advantage of the new possibilities as well as to bring building construction to a new level, knowledge in fields of mathematics, material science and others must be deeper integrated into the process.

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I Mirabilia: Taking Care of the Emotional Life of Hospitalized Children

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ABSTRACT

Mirabilia (“The Wonders”) are a family of three interactive dolls for children who spend a long period of time in hospital, due to terminal illnesses or periodic therapies. Drawing on interviews and observations in a children’s hospital, three dolls were designed to help overcome specific emotional difficulties faced by children in this situation. The different interactions and behaviors triggered by the dolls enable the children to improve their relationships and make new connections with the people within the hospital, such as doctors, psychologists and other hospitalized children.

Keywords

Children in hospital, dolls, emotional needs, psychotherapy, non-verbal communication, haptics, tangible interfaces

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Designing Smart Textiles for Music and Health

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ABSTRACT

In this paper we present our ongoing research on designing smart textile solutions for musical tangibles, what we call co-creative tangibles. Our textile, musical tangibles shall be used to improve health and wellbeing for children with severe disabilities and their families, in their homes. We use theories from the Music and Health field as a framework, both for the design process and the design related user evaluations. Building on an ecological and holistic health approach, our main goal is to reduce passivity and isolation, for the child with special needs. To achieve our overall goal, improve health for the users, our textile, musical tangibles have to evoke feelings in the user, be possible for the users to master, create and strengthen social relations and give the users a feeling of wholeness. Because of our ambitious goal, the diversity of users and the varying everyday situation, our musical tangibles have to offer the users a variety of musical actions to perform, and continuous choices of intensity levels and focus of attention. If not, the musical tangibles will lose their interest fast, and lack the relation building qualities we need. Our Music and Health approach therefore demands our textile, musical tangibles not only to be used as an instrument in limited therapeutic session, but in many situations in the users' everyday lives.

Keywords

Smart Textile, e-textile, Interaction Design, Tangible Interaction, Music, disability, special needs, Universal Design, health, children, Ubiquitous Computing, musicking

INTRODUCTION

Smart Textile, Interaction Design, Tangible Interaction

During the last decade a wide range of experiments and exploration in smart textile expression has taken place [4, 22, 7, 29, 33]. But rather few of these experiments have lead to actual products, or been used in real use situations, with a few exceptions. This partly depends on the professional and academic environment that has driven this development and their focus, textile and fashion design. Partly it depends on all the technical limitations we still

struggle with, in this field, like battery technology and washability, to mention two.

From the late 90ies the field of Human Computer Interaction (HCI) has developed from focusing on the ergonomics of the computer screen interface, to the field of Interaction Design, where aesthetics, actions and time is the important design dimensions [19, 20].

During the same time Ubiquitous Computing has developed from HCI and the initial vision of the disappearing computer [32], to a fast growing research field, where smart textile becomes increasingly relevant. The Ubiquitous Computing field has followed a similar path as Interaction Design, by first focusing on the surface of the computer, the user interface, to later broaden its perspective [30]. One of the pioneers, Hiroshi Ishii, defined the field as something else then screen and keyboard, a tangible user interface [17]. He called it TUI, as an opposite to GUI, the current Graphical User Interface. This computer surface focus has later developed to a deeper understanding of the physical, social and cultural experience of embodied and tangible interaction [13, 14, 15]. Theorist like Paul Dourish, and Bruno Latour [18] have broadened our understanding of what we do when including computer hardware and software into our everyday things, which themselves carry social and cultural meanings. This understanding expand the design challenge; From focusing on the interactive object, it's shape and surface, we have to take into account the complex social and cultural situation we design for. We create complex hybrid things, when we include hardware components like "Intel inside" and software components like "Google search" into our own designs. These components are parts of a complex network of meanings and value in complex actor relations. Therefore, things cannot longer be valued isolated from its complex value networks. This means that we design for situations and uses we have never thought of. A classical example here is of course the iPhone, where new Apps continuously change what it is for each and everyone of us. Before iPhone, a mobile phone should look like a telephone, now this has become irrelevant. The design challenge expands to many levels, where the thing itself is only one level, which have to be open to staging in many relations and situations [9].

We have used considerable space on this research field introduction, because it is essential to how we understand our design research challenge in this complex landscape.

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Further we think we might see a similar development in the Smart Textile field, developing from a world of patterns, surfaces and textures on fabric in meters, to a component and service based world.

Interaction Design, musical actions and musicking

Educated as industrial designer, working within Interaction Design and Tangible Interaction, focusing on music interaction and creating musical tangibles in smart textile for disabled, this complexity becomes obvious. On one hand there is a long tradition of acoustic musical instruments and musical performance skills, related to the instrument. Traditionally, musicians don't problematise their instrument, its' role and potential. It feels natural that the sound comes from the place, and at the same time, as one interacts. However, some music researchers have broadened their understanding from an instrument as just a musician's tool, to an artefact with agency [12].

Computer based instruments can be programmed to work very differently from acoustic instruments, that sound immediately, corresponding with the musical action. A weak hit at one place, can be programmed, to be heard and seen, as a sound and light after some time at a totally different place. As interaction designers we can design these kind of shifts in time and space to motivate a movement from one place to another [10]. And thereby create expectation, differently from what acoustic instruments can. In this way we can design and program the computer to take different roles in a use situation. It might be like a controllable instrument that answers immediately at the same place where the user interacts. Or, one can program the interactive artefact to answer after a hesitation, as a communicating friend or an improvising musician [11].

Musicians have a wide and great understanding of musical gestures and actions, that we lack in the field of Interaction Design, mostly focusing on buttons, and where response time most often is a negative experience. In real time interaction like musical action, varying in time and space, is part of the aesthetical music experience. When focusing on music playing on an instrument the response time is often pleasurable, because it is set to a musical event with rhythm, harmonic and melodic development during the response time. Music therefore brings the industrial and interaction designer from an interface oriented focus to an aesthetic action oriented focus. On the other hand the designer has knowledge of use, materiality, shape, structure and the potentiality of computers, that a musician handling his instrument as natural given, don't even think about. So the multidisciplinary approach is essential in this kind of pioneering work we try to do.

Music theorists, focusing on the everyday life experience of music, have problematised the mediation [12] and action [31] level of music related activities. With the term "musicking" Christopher Small sees music as a verb, a meaning making activity that includes everyday listening, dancing, creating and performing music. This is a very

fruitful and important concept since activity, social sharing and inclusion is important in our project to achieve. Central in Small's musicking term is the social activity and experiences, where all participants present are equal, no matter level of expertise or activity. But neither Tia DeNora nor Small has treated computer based instruments, and their specific possibilities.

When studying, designing and evaluating possibilities offered by computer based instruments, musical tangibles, it is important to work on many levels simultaneously. It is important to explore both the material, action related, social and cultural level to achieve our overall objectives. Here, the smart textile explorations related to our health goals, become one important level in our design process of creating new *co-creative tangibles*.

Music and Health

During the last 15 years the positive health effect of music has been heavily documented within biomechanical and humanistic health approaches. The biomechanical health approach focus on the quantitative measurement of health indicators, like blood values and heart rate. While the humanistic and ecological health approach focus on health as an experience of wellness and life quality [6, 5]. We relate to the latter in our research.

Here, music as a cultural expression is being used to reduce passivity and isolation. It can evoke feelings make it possible for people to cope with the situation and strengthen and create social relations and sense of wholeness [25, 24].

Smart Textile for Health improvement

Built on our earlier arguments, smart textile solutions for health improvement are, for us, textile solutions that evoke the users' feelings, give the users a feeling of mastering and meaning in the situation and mediate and strengthen the users' social relations. Further on in this text we will show our practical design explorations in textile, and how we worked with a material way of thinking [21] in designing smart textiles solutions to achieve these goals.

THE RHYME-PROJECT

The framework and basis for this paper is the RHYME-project. The project is a multidisciplinary project between the Centre for Music and Health at the Norwegian Academy of Music, Institute of Design at Oslo School of Architecture and Design and Institute of Informatics at the University of Oslo. The goal of the RHYME project is to improve health and life quality for persons with severe disabilities, with use of "co-creative tangibles". These are computer based, networked and multimodal things, which communicate following musical, narrative and communicative principles. They are interactive, social, intelligent things that motivate people to play, communicate and co-create, and thereby hopefully reduce passivity and isolation, and strengthen health and well-being.

Through the five years (2010-2015) the project will last we will develop new generations of co-creative tangibles every year focusing on different user situations.

Method

Multidisciplinary and Research by design

The RHYME project is multidisciplinary, joining competences from Music Therapy, Music and Health, Psychology, Industrial Design, Interaction Design, Musicology, Music Composition, Computer Science and Universal Design.

Our design research methodology is user-centered and practice based, where we develop knowledge through design of new generations of co-created tangibles [27, 28].

Action oriented empirical studies

Our user studies are action oriented [16, 3] and multidisciplinary. In our latest study we observed 5 children interacting together with their care persons. We made 4 different actions over a period of 1 month at a school for children with special needs. From one action to the other, we made changes based on the previous action, weekly user surveys, observations and multidisciplinary discussions. All sessions were video recorded from three angles.

Future actions and observations will include families and siblings and be made at home, at school and between different environments.

FIRST GENERATION TANGIBLES – ORFI

The first empirical study in the RHYME-project was of the ORFI installation (Fig.1), created earlier by three project members. ORFI is a tangible, cross-media installation, and a result of over 10 years of explorations within the field of tangible user interfaces for music related activities [1, 2, 8, 11].



Figure 1. The ORFI landscape, the modules and the dynamic video projection.

ORFI consists of 20 tetrahedron shaped soft modules or custom made cushions. The modules are made in black textile and come in three different sizes from 30 to 90 centimetres. Most of the tetrahedrons have orange origami shaped “wings” mounted with an orange transparent light stick along one side. The “wings” contain bendable sensors. By interacting with the wings the user creates changes in light, video and music. Two orange tetrahedrons contain microphones.

ORFI is shaped as a hybrid, a hybrid between furniture, an instrument and a toy, in order to motivate different interpretations and forms of interaction. One can sit down in it as in a chair or play on it as on an instrument, with immediate response to interaction. Or one can talk, sing and play with it, as with a friend and a co-musician in a communicative way, where ORFI answers vary musically after some time. Every module contains a micro computer and a radio device, so they can communicate wireless with each other. The modules can be connected together in a Lego-like manner into large interactive landscapes. Or, the modules can be spread out in a radius of 100 meters. So one can interact with each other sitting close or far away from each other. There is no central point in the installation, Instead it is like a field [8] of many potentialities. The users can look at each other or at the dynamic video they create together. Or one can just chill out and feel the vibrations from the music sitting in the largest modules as an immersive, ambient, experience.

Observations, Findings and New Challenges

From our action oriented, multidisciplinary user study we found several weaknesses with ORFI, and many desired qualities, that we wanted for a new generation of co-creative tangibles; In particular the music therapists and Music and Health professionals wanted the sound source to be close to the interaction place, similar to how acoustic instruments work. For interactive objects, it means to place the input sensor close to the speaker. This is a complex design challenge regarding wireless objects, object size and weight, sensor qualities, sound quality and wireless sound transmission.

Equally, we wanted a closer relation between the interaction place (sensor) and the light output.

Further we want to be able to install the co-creative tangibles in families’ homes in the future, which represent huge design challenges. Just turning all the wireless modules in ORFI on and off, and charge the batteries currently represent a big job. The big fixated projection is also currently too intruding and complicated to install in peoples home. We also wanted to explore more sensory stimulation like vibrators and stronger speakers, and create more easily enabled input sensors.

Finally we wanted to be able to integrate microphone, speakers and camera for new cross-media interaction possibilities.

SECOND GENERATION - WAVE

As an answer to the described challenges, we have created the Wave concept. For the moment, Wave consists of the wired Wave carpet and the wireless smartphone based Wave beanbag-like chair. The Wave carpet, which we present in this paper, is size 3.5 x 3.8 meters. It is wired to the power grid and consists of seven wing-like arms (Fig.2). Two arms contain digital bend sensors. Two arms contain accelerometers, which register movement in three directions. One arm, in the middle, contains a microphone, and the last two contain projector and web camera. All arms have orange velvet tops that lighten up during interaction. To activate the camera and projector, the user holds on the orange, soft, velvet touch sensors, and the light goes on (Fig.4(5)). The microphone reacts to the sound level, and record, when activated by relatively higher sounds (Fig.4(3)). The big body-like parts of the carpet are in dark blue-gray car textiles, in plush and twill, with embroidered and embossed wave patterns (Fig.5(2)). The carpet is filled with different kinds of fill, that gives it a “landscape” structure. The carpet “body” contains speakers, vibrators, computer and connectors, but not any battery since it is connected to a wall socket. It communicates wirelessly. The reason for choosing a wired solution was the possibility to explore power demanding sensory stimuli like vibration.



Figure 2. Detail (1) and Shape (2) of the Wave carpet.

Design explorations

We have a user-centered and research-by-design approach in our design research. Design explorations therefore is an important ground, for our knowledge development. In this paper the focus is on the textile related design challenges, and only briefly touches the interaction and musical aspects of the design.

In the following, we will present and argue for how we designed the textile solutions, the textile carpet and textile related experiences, to accomplish our health related goals. The textile tangibles we create in the RHYME project, are to be used for collaborative musical play and musicking experiences. Therefore we call them co-creative tangibles. The goal is, with and through use of these textile objects, to motivate diverse users evoke feelings, be able to master over short and long time, strengthen social relations and give each user a feeling of wholeness. These goals are based on Music and Health research, which is the ground for the project. In the following, we will show how we have worked with the textile design to reach our goals.

Evoke feelings with smart textile

There are many ways to engage and evoke feelings, both positive and negative. In smart interactive objects the possibilities lies both on a physical design/hardware level

and an interaction/ software level, and the combination of the two, to change over time.

Limited smart textile possibilities

With our rigorous requirements, to be engaging for the diverse users and durable to user testing over long time, many smart textile possibilities are not relevant for us. Many possibilities, like thermo chromatic printing or yarn, react too slowly to be interesting. Other solutions, like memory materials or temperature changing yarn, are both too slow and fragile, to be of use for us. The many stretch sensors we created and tested so far, are not yet durable enough, for our use challenges. Solutions like RFID that require two parts (sender and receiver), are too difficult to use, for our target group. Further, light has to be embedded, to give a nice surface, and be protected from the child's scratching and bending. The wires we use have to be able to position and lie on top of each other, in any direction, and be bended many times, since our goal is to engage and activate. There are also other problematic safety aspects we have to take into account, regarding weight, height and voltage level, when working with disabled children. All these aspects and requirements are relevant for the smart textile design.

Engaging and comfortable on the floor

The floor is for most children a safe place to be. There is no danger to fall down and hurt oneself, when sitting or lying down. For people in a wheel chair this is not always the case, since the wheel chair becomes an extension of their bodies. The wheel chair makes them move, sit around tables and participate in the sitting world. But when others rise up, they still sit, and see the street and other places, where we usually walk, from a sitting perspective. So moving functionally disabled onto the floor sometimes make them unsecure, even if children usually feel very safe on the floor. Adults also sometimes feel that sitting on the floor is childish and uncomfortable.



Figure 3. Man sings into the glowing microphone and interacts with his hand on the interactive touch sensor field.

Therefore, for the Wave solution, we chose the floor as the place to be; The place to meet on equal terms. From the user study of ORFI, we observed how a carpet could function as marking the place for play. It became the warm and cozy place to share. We therefore created an interactive "landscape carpet", and embedded the multimedia components into the carpet, instead of spreading out, and separating them from the interaction spaces, as we did with the ORFI installation. As mentioned before we wanted to create tangibles, that were easier to bring into peoples' homes. Here, the projection seemed to be one of the challenges to include in the homes, since the big screens usually still are the television set in the living room. Occupying the television would be too intruding. So we decided to include a handheld movable projector into the Wave carpet, instead of the fixated projection on the wall that we had in ORFI (Fig.1). We also included a camera into the Wave carpet, so one could continuously record and project all over, also onto the textile as a new layer of patterns on the textile.

Further this opens up for a new way of cross-media co-creation, to play with ones identity in visuals and voice (Fig.10).

Playful and body-like shape

The Wave carpet consists of seven "arms" (Fig.2). Each arm is input or output devices, some both, to play and interact with. All arms have funny looking orange lighting tops, which lights up when someone interacts with the sensors. The many arms with their glowing tops and the three divided shape, gives the carpet a playful and creature-like expression, soft and fun to play with in many ways. We have work hard to give it an ambiguous expression, to meet both adults and children. To balance on the edge, and create a more "haut couture" furniture expression, to give the most advanced to the most needing.



Figure 4. Details of the arms and their glowing tops. From top left: Bend sensor (1), Activating the bend sensor and top glows (2), Man singing into the glowing microphone (3), Activating the accelerometer (4), Touching the camera touch sensor (5), Playing on the interactive touch sensor field (6).

Contrasting colours and textures

The contrasting colours and textures strengthen the expression of playfulness. The glowing fragile burnout (devoré) velvet fabric, contrasted by the thick robust car textile invite to different kinds of interaction just by the quality of the textiles. The contrasting embroidery and sewed textile structure, gives the surface direction, paths to touch and places to interact.



Figure 5. Man singing into the glowing microphone and interacts with his hand on the interactive touch sensor field. The different wave textures combining embossing, machine and hand embroidery velvet integration.

Soft and three-dimensional lighting interaction spaces

One of the many challenges we had with ORFI was the input sensors. For some of the weak children, bending the wings was too difficult even if one could press, squeeze and touch in different ways. This time we wanted to create a sensor that was easier and more desirable to interact with. We therefore wanted to create a soft touch sensor with tactile qualities that lighted up on interaction. Further we wanted to make the interaction place itself illuminating, so the user got immediate response in light. In textile this means to embed the sensor and light at the same place. Most touch sensors on the market are hard or need a hard surface to function properly. But we wanted a soft and tactile textile sensor. We decided to try to work with infrared, or IR reflection sensors and embed them into our soft textile objects. But IR sensors react to the change of daylight, so being in an everyday situation, not in a controllable test space or gallery, we had to isolate the sensor from the daylight. Another problem we had was the sensor itself. Under a soft surface one could feel it, which we did not find satisfying from a tangible and aesthetic point of view. We therefore submerged it into a soft foam (Fig.6), and secured it from daylight coming from underneath and all sides.



Figure 6. IR reflection sensor close up, Submerged into foam, Covered with light reflecting fill.

We did several reflection tests with various materials. IR reflection sensors contain both an IR light, which our eyes cannot see, and a light sensor reacting on IR light. The sensor reacts when one holds something over it, that makes the IR light reflect back. Placing soft polyester foam over the sensor, and pressing it makes the reflection vary depending on the pressure. This gave us an analogue and soft touch sensor. In the first versions we used a big piece of white polyester foam to cover the whole field of sensors. But when pressing on the foam it stretched and affected the surrounding sensors, why we decided to cut the polyester foam into pieces (Fig.6)

Our next challenge was to isolate the sensor from daylight. We tested several materials, but materials like plastic produce sound when squeezing it, and this we did not want. We ended up making a totally light isolated package in neoprene (Fig.7).



Figure 7. The neoprene component, map of the sensors location, Upper-layer in car textile with holes matching the sensors.

The neoprene package made a very robust package of sensors, maybe a future component, but not glowing or very inviting.



Figure 8. Diverse light tests, light spreading material, transparent cover material and tactile qualities. From top left: Interaction tests and light spreading with RGB LEDs (1), Burnout velvet and RGB LEDs (2)(3), Light spreading in white fill (4) and multi coloured wool (5), Integration of burnout fabric into wool (6), white LEDs and orange wool (7), Diverse Wave textures (8)(9).

We needed tactile and transparent textile to create an inviting surface. Again, we had to start with the electronics, trying to find a satisfying LED with acceptable voltage level and Ampere to work further with. We did many systematic experiments in various textile techniques. We cut thick textile and laminated with transparent material. We knitted holes and knitted nylon/wool material to burnout (devoré) transparent spots for the lighting sensors. And we did burnout and dyed velvet to make a soft, desirable transparent material. We tried coloured light with white foam and white light with various coloured wool and foam (Fig.8).

We ended up using the dyed and burned out velvet which we mounted into cut holes in thick plush car textile (Fig.9). We used RGB coloured light diodes and sewed structures into the car textile to create more dynamic expression.

The result, when touching, became a very soft, tactile and amazingly glowing and sounding experience. The downside is that the burnout textile might be fragile, on the other hand the interaction field, as it is designed, offers a very sweet expression inviting the user to pat gently.



Figure 9. The interactive sensor field in burnout velvet.

We later developed the sensor further, but used ordinary Light Dependent Resistors (LDR) and a LED. This functioned even better.

Three-dimensional texture patterns directing towards interaction spaces

Building on the Wave concept, we sewed wave structures into the car textile to make it more foldable and inviting to interact with. The direction of the Wave structures went from one sensor to the other in pair. So the textures communicated interaction, dynamics and direction (Fig. 3).

Respond immediately in sound and light

An important function, when working with disabled children in a Music and Health and Music Therapy context, is to give the children immediate response to their actions. Here is one unique possibility the computer can offer, that an acoustic instrument cannot, because it is limited to its material and mechanical conditions. With the computer one can give a full response, in for instance sound or light, to a very weak hit. Opposite, one can give a gentle response to tough interaction, to invite to rhythmic and musical gestures. But there have to be an immediate response to

motivate the child to feel an ability and desire to continue. In ORFI we had immediate response in light inside the wings, but many had hard time recognising. Since one mostly looked at the outside, the inside purple velvet with light became a mysterious secret known to a few initiated. Therefore, in Wave we designed our solution to give immediate and easily visible response in light and sound to any user interaction.

Invites to play

One of our main assumptions, that will increase wellness and health, for our user group is activity. So, if our co-creative tangibles can engage and activate the children, we have achieved many of our goals. An acoustic instrument only sounds, when you play on it. But interactive networked things can be programmed to behave otherwise. The interactive tangibles can invite the users to play, by playing a tune, or light up after shorter or longer time in silence and darkness. After a weak answer from the child it can play rhythms with a pulse, to motivate the child to interact and follow the rhythms to collaborate further. The co-creative tangibles can be used to improvise and invite the user to further interaction and play on their own terms.

Able to master the textile experience

Mastering is an important issue in the field of Music Therapy and Music and Health. It is a learning related term and involves paying attention, being able to respond and act in a sequence, to explore freely and to perform socially rewarded acts [23]. Related to our interaction and textile design point of view, it is important to create tangibles that offers both stable and dynamic qualities. Stable, to motivate feelings of control, order and openness to explore freely in any sequence. Dynamic, to motivate the user to perform musical interaction patterns and narratives. Again, it involves the combination of the physical design potentialities with complex software development, building on musical improvisational techniques. We here concentrate on the smart textile related and physical design solutions.

Soft and accessible on the floor

The floor is a place where everyone can meet on equal terms. The risk that someone with less ability to move can fall, or in other ways hurt herself is minimal if the flooring material is soft. Therefore we choose the floor, to offer everybody the same accessibility. But people are different. Some requires tangible three-dimensional support like volume and filling, while others do not. Therefore we chose not to make a flat carpet, but instead work with different qualities of filling, in order to offer everybody equal opportunities to interact and yet co-create in their own manners.

Ambiguous shape invites to different actions

One of our main assumptions is that aesthetically ambiguous experiences can increase wellness and health by inviting people to do many different actions [1, 8]. Wave's

ambiguous shapes with different filling and tangible responses, invite the users to make different actions. Everytime a user interacts with a new shape, he or she gets a response, that is contrasting to the response of one of the other shapes. It therefore invites the user to explore many possible actions and sequences, instead of only one, or repeated actions.

Heterogeneous shape combines bigger and smaller differently manageable parts

The Wave carpet consists, as earlier described, of seven arms, more or less with the same wing shape, connected together at the middle (Fig.2). Each arm is between seventy to ninety centimetres and with a filling depending on the kind of sensor they contain. The two bend sensors are stiffer to be easier to bend, compared to the one with accelerometer (Fig.4). But the bend sensor arm is still soft so one can bend, squeeze or jump on it to interact. The arm containing the camera is longer, thinner has a harder end, so it is easy to grip and hold on the sensor that activates the camera (Fig.10). One can lie on the carpet and bend the sensors towards one self, or just move the arms and play and "dance" with them more freely outside the Wave carpet. An unstable child might find comfort in holding onto an arm, when playing. The heterogeneous shape with many arms offers many ways to play and manage the parts, both weight wise and size wise for diverse users.

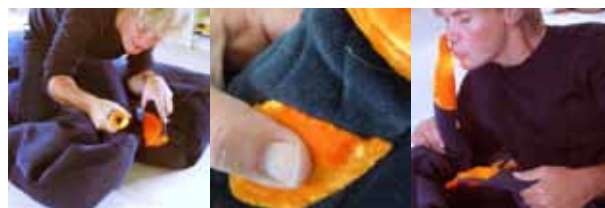


Figure 10. Man playing with the camera and projector, activating the camera and the microphone with his voice.

Multitudes of interaction possibilities invite to diverse interaction forms

Each arm contains different sensors, and the carpet therefore offers a multitude of interaction forms; You can bend, jump on or twist the bend sensor arms. Dance or wave with the accelerometer arms. Talk, sing or blow into the microphone, or just let it record the actions and sounds taking place. Or you can play on the interactive bubble field as buttons, or just hug or stroke it like a cosy kitten (Fig.4,5). And you can do all or any combination of it all. Or one can just listen to the music playing, remembering and varying the memories accompanied with sound and visuals. And let the projection play the "visual memories" onto the wall or floor. Nothing is wrong. Everything is right and hopefully manageable for everyone on their own terms.

Feasible and sensitive sensor interaction places invites to different activity levels

The many interaction possibilities open up for endless ways to play and interact with the Wave carpet. It also includes

endless ways to interact and vary activity level and interaction patterns over time. Children with special needs often gets tired more often, so it has been of great importance to offer a possibility to rest and calm down in-between more intensive interaction periods.

Simple and complex interaction possibilities make it challenging on different ability levels

The many interaction possibilities, regarding input devices, activity levels, interaction sequences and the advanced musical improvisation computer programs, that vary the response musically, offers the user possibilities to learn and master both in a physical and musical way.

Creation and strengthening of social relations

We know from health research, as mentioned in the introduction [25, 24], that passivity and isolation reduces health and wellness. Therefore creation and strengthening of social relations is important. Children with special needs in western societies are usually activated by people in the social system around the child. Often the relation between care person and child becomes unequal. Our goal has therefore been to create tangibles that activate the child on his or her own terms and own time. Since the computer has unique possibilities and can be programmed, it can for instance wait and be patient, which we humans not always are.

Soft and large tangibles invite diverse users to interact together on the floor

The large size of the Wave carpet offers many ways to share the physical, visual and musical experience. Many people can sit around the carpet and interact with the arms. Or two or three people can sit physically close to each other on the soft carpet and reach the arms or pull them over themselves, which gives a warm, close and sensory shared experience.

Foldable shape motivates various use, co-creation and play

The carpet consists of three parts designed to be folded together, and be used as a big backrest cushion. When folded, the arms stick out on each side like a stack of soft sticks easy to reach when leaning against it. The middle, main part of the carpet contains speakers and vibrators giving an additional sensory experience, when leaning against it. It further motivates users to move, play and co-create.

Many movable parts in pairs motivate dialogue and rhythmic actions

The many arms, grouped in pairs, invite to play and imitation between two or more users. One pair is the bend sensors, with the orange wave pattern and rather stiff structure. Another pair, is the tail-like accelerometers in soft plush fabric, and yet another, the camera and projection pair (Fig.4). All the pairs are placed so that one can either place oneself on one of the long sides controlling one kind of sensor. Or one can place one self on a short side and

control one of each, with the camera and projector pair as a special pair. Either one person both records and projects, or two persons share and use the camera and projector separately. Either way it invites to a dialog and rhythmic interaction, while changing between positions and pairs around the Wave carpet.

Diverse interaction sensor types and designed textile qualities motivate users to take different roles in the co-creation

The diverse kinds of input devices open up for the users to take different roles, and shift roles by controlling different devices over time. This opens up for a more changeable and flexible co-creation session. Because of the Wave carpet's flexibility in interaction forms, roles and intensity levels, it can be more motivating over long time.

Robustness of the textile to motivate rough bodily and social interaction

The main part of the carpet is made from two kinds of dark blue-grey plush and twill-woven car textiles, contrasted with orange glowing velvet fabric (Fig.5). Into the plush car textile we sewed embossed wave patterns in the same colour with a simple hand embroidery wave-like line. On the other twill woven car fabric we sewed orange contrasting waves to stand out. The filled car textile gives a very soft, rough and bodily experience, which invites to rough activities.

Rhythmic light dimming to motivate in-tuned rhythmic interaction

The light and sound response is programmed after musical improvisation rules, following musical pulse, to motivate in-tuned interaction. The light gives a visual pulse to follow and tune in to, supported by the musical pulse. We work with many layers on the visual and musical output to motivate musical interaction and improvisation. First, it is always a layer of direct response to the actual interaction. Secondly, there is a layer of the co-created musical and visual rhythm and thirdly, there is the genre pulse that gives an overall soundscape [26]. In these layers we also build up the light and visual output, to motivate musical and rhythmic musicking and co-creation.

Experience of wholeness with textile tangibles

The experience of wholeness [25] is a complex experience of understanding, meaningfulness and being part of something larger than one self. When trying to use this as a requirement for the design, of the musical tangibles, it easily becomes very simplified and trivial. Even if we are afraid of doing exactly that, we have to try to use our design skills to mediate and achieve our ambitious and complex goals.

Being on the floor and ground

Again, being on the floor, at home on a thick soft surface, offers a feeling of freedom, and of being literary grounded, close and on equal level as the person next to us.

Covered with heavy soft textile gives a feeling of being held
 Since the carpet is created of parts, and can be folded, one can lie on one part and cover oneself with an arm or a whole part. To be covered with the soft, thick car textile gives a feeling of holding and being held, which often is used physically and musically in Music Therapy. When putting speakers and vibrators on to ones body they expand and strengthen the sensory experience.

Full body interaction on the floor gives an experience of being childlike, grounded and in contact with oneself

The full body interaction offers a feeling of both being vulnerable and safe at the same time. The possibility of being physically close to others on the floor, are for some an ambiguous experience, that depends on the person's physical confidence related to others, and the interpretation of the overall situation.

Shared social and bodily co-creation strengthen the experience of wholeness

The many possibilities to take part on one's own term in the interaction, co-creation and musicking experience, mediate and strengthen the experience of wholeness, and of a socially shared experience. The co-created soundscape makes one part of the social experience, even if one does not interact and perhaps stand aside, observing what's going on. The music has a so called attention-trapping impact [23], as it creates expectations and thereby mediate the socially shared experience. The physically and bodily shared experience of interacting more or less intensely, in any way one wants, without feeling that there are right or wrong ways of doing it, also strengthens the feeling of a co-created experience of wholeness.

CONCLUSION AND FURTHER

In this paper we have presented our ongoing work in Smart Textile related design, in a Music and Health context. The RHYME-project, which is the basis for this work, has a health and wellness related goal, and therefore, the smart textile designs are subordinated that overall goal. The project is based on the last 15 years' research in Music and Health and over 10 years experience of designing musical tangible art installations, in an art and design context (MusicalFieldsForever). But nearly nothing in the Music and Health field, has until now, been done regarding interactive and computer based instruments and artefacts. The project goal is to increase health and well-being for children with special needs and their families through use of musical tangibles. These musical tangibles, which we call *co-creative tangibles* are *not only* instruments, but mediate a broader social *musicking* experience. All our co-creative tangibles are and will be made in textile, because of its softness, the potentials that lie in textile traditions and our ambitious goals. Therefore, finding e-textile solutions to embedding and creating the input and output devices as *active structures* in the textile, represent big challenges for the current design work. Since our goal is to investigate

health effect through long lasting empirical studies the designed artefacts, the co-creative tangibles, have to be desirable, inclusive and very durable. Consequently most of our smart textile solutions are limited to that aim. Because of our overall goal, the everyday situations, and the diverse users, the challenges are even broader. Therefore the textile design challenge includes both the use context, cultural traditions related to the artefact, and the different user opinions, as requirements into the design process. And always keeping in mind the health related goals to; *evoke feelings* for all the different users and context, be *possible to master* for diverse users, create and *strengthen their social relations* and create a *feeling of wholeness* for all users' diverse needs and wishes, regardless of activity level or ways to relate to the artefact. We have shown how we have thought and designed the smart textile solutions to meet these complex challenges, both related to cultural form, shape, interaction forms and social experience.

The upcoming spring we will conduct a comprehensive action based empirical study on the Wave carpet and other Wave tangibles, to evaluate and formulate goals for the next generation of prototypes.

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Figure 11. Man sings and rocks himself to sleep.

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Aura: Wearable Devices for Non-verbal Communication between Expectant Parents

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ABSTRACT

Aura is a set of wearable devices to enable non-verbal communication between expectant parents. The project investigates possible aesthetic experiences as alternative applications to biometric monitoring. It aims to overcome the current situation in which the pregnant woman is seen as mainly and merely either as a patient or a “blessed body”. To achieve this, medical staff and potential users were interviewed. Based on the outcomes we designed a service embodied in two devices: a garment for the expectant mother and a bracelet for her partner. Fetal movements are translated into a light message for the mother-to-be and into a haptic one for her partner. The simultaneous connection of the partners enhances the emotional messages transmitted by the devices. The relationship is participator and the actions of both partners shape the conversation.

Keywords

fetal movements, design as research, pregnancy, evocative communication, wearable computing, biometric monitoring

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Smart Textiles - Safety for Workers in Cold Climate

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ABSTRACT

The cold and harsh climate in the High North represents a threat to safety and work performance. Clothing equipped with sensors that can monitor the workers and give an “early warning” before working condition approaches dangerous levels. In this project a demonstrator consisting of a working jacket with integrated sensors and wireless Bluetooth Low Energy (BLE) communication has been developed. The sensors used were an IR temperature sensor for measuring skin temperature, and two combined humidity and temperature sensors for monitoring the conditions inside and outside the jacket as well as the insulation properties of the jacket. The demonstrator jacket was tested in the work physiology laboratory at SINTEF using reference temperature sensors in warm (+22 °C / 50 % relative humidity (RH)) and cold (-5 °C) climatic chambers. The result showed that there was a clear relationship between the reference temperature at the finger and IR sensor measurements that can be used in the future as a tool to give early warnings of critical temperature limits for manual performance. The demonstrator can provide easy accessible information about the thermal conditions at the site of the worker and local cooling effects of extremities. This information can be used in an enhanced safety perspective, as an improved tool to advice outdoor work control for workers in cold climate.

Keywords

smart textiles, safety, physiological sensors, wireless

INTRODUCTION

Petroleum activities moving further north implies that workers will be exposed to extreme rough weather conditions (cold, snow and ice) that can lead to fatigue, impaired physical and cognitive performance [1,3,6].

The interaction between the thermal environment and performance of the workers in cold environments is largely dependent on how the body can compensate physiologically for thermal strain [4]. The most obvious effects of work in the cold are distraction and reduced

manual dexterity associated with local cooling of finger and hands [2]. Finger and hand temperatures of 15°C and below are closely related to severe loss of manual performance [5, 10]. There are several methods for assessment of cold stress. The most widely used index for workers in the cold is the wind chill index (WCI) to assess the risk of freezing of the unprotected human skin [6]. ISO 11079 provides recommendation on required clothing insulation and exposure times in the cold [6]. However, no standard exists today that provide easy accessible information about the thermal conditions at the site of the worker or local cooling of finger and hands. Knowledge of the physiological responses of the workers can provide more exact information about the critical temperature limits for safe performance in cold environments.

Safety of the workers is significantly affected when temperature decreases [9]. At the same time there is high cost attended with temporary shutting down e.g. a plant due to rough climate. Therefore, the need for using the right criteria to abort work is essential. It is of interest to have knowledge of ambient conditions (e.g. temperature and humidity) at the site where the workers are operating, as well as inside the clothing close to the skin to provide essential information about physiological threshold limits for safe performance in the cold.

We hypothesized that sensors can be integrated in clothing to provide information about ambient conditions and physiological parameters in a way that enhances the safety of workers in cold climate without disturbing the user.

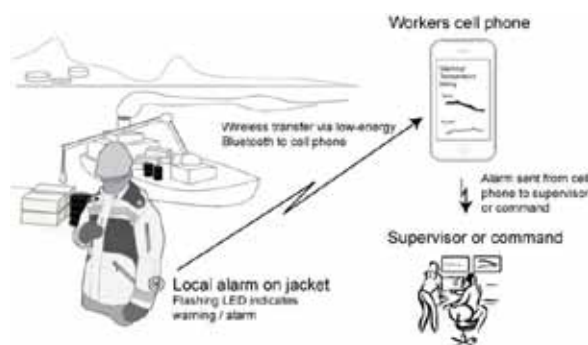


Figure 1 A scenario of the sensor system in use - provide enhanced safety for workers in cold climate.

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DESIGN AND TEST OF SENSOR SYSTEM

In this project a demonstrator consisting of a working jacket from Wenaas AS (<http://www.wenaas.no/>) with integrated physiological sensors and wireless Bluetooth Low Energy (BLE) communication to a handheld device was developed. Figure 1 shows a scenario of the sensor system in use.

Electronic sensor system

The demonstrator is composed of three main parts; integrated sensors and LED alarm, integrated printed circuit board (PCB) with BLE and a handheld device with software to process, store and display sensor data (Figure 2). BLE is a state of the art technology aimed at low-power and low latency applications for wireless devices within a short range (up to 50 meters). BLE will typically be implemented in small devices like watches, sport belts, cell phones, tablets, up to larger devices like laptop computers, desktop computers etc.

The size of the sensor system is crucial to not alter the usability and the characteristics of the jacket. The user must not be disturbed by the sensors and necessary equipment to read and wirelessly transmit data from the sensors.

The BLE was chosen because it only consumes a fraction of the power of classic Bluetooth enables products. The BLE chip can interface directly to the sensors and transmit data so no extra integrated circuits (IC) are needed. This enables a small device running on a changeable button battery with very few components needed.

A small PCB containing a BLE pre-evaluation IC from Texas Instruments powered by a button battery has been developed to fit inside the jacket. The module has multiple connectors for connecting the sensors.

At the time of this project no commercial BLE enabled products was available. The handheld device in this demonstrator was therefore a portable computer using BLE pre-evaluation kit from Texas Instruments and a SINTEF developed LabView program. The LabView program is shown in Figure 2 to the right.

Choice and location of sensors

When exposed to severe cold, blood vessels in the extremities are constricted to reduce blood flow and allow cooling of muscle and tissue in the peripheral parts. Local cooling of the extremities has a detrimental effect on manual performance [2], but minimizes the total heat loss and maintains temperature in core areas. A study performed on petroleum workers working in cold conditions showed that finger temperature was an important indicator of hand and finger dexterity and that finger skin temperatures below 20 °C resulted in impaired manual performance [10]. Due to this, real-time information about skin temperatures on hands and fingers could function as an early warning to prevent the risk of

reduced manual performance and hence ensure safe and proper accomplishment of tasks.

A sensor system should ideally be positioned in a glove close to the fingertip, but this is however challenged by the fact that the workers often take off their gloves when performing assignments requiring fine motoric precision.

The sensor system has been integrated into the lower left sleeve facing away from the body, see Figure 3. This position was chosen because it is close to the hand, but still avoiding extensive wear and tear and conflict when carrying or lifting objects.

Sensiron SHT11 was used for measuring temperature and humidity. The sensor is aimed at high-quality relative humidity measurements for demanding environments and is fully factory calibrated. One sensor was placed on the outside of the jacket whilst the second sensor was placed on the opposite side of the sleeve on the inside of the jacket. The two opposing sensors will provide data on the qualities of the textiles such as insulation and humidity transportation capabilities.

An infra-red (IR) thermometer for non-contact temperature measurements, MLX90615 from Melexis, was attached to the inside of the jacket and used to measure skin temperature on the upper hand/wrist. The IR sensitive thermopile detector chip and the signal conditioning application specified IC are integrated in the same miniature package and the small size makes it especially suited for integrating in clothes. The thermometer was factory calibrated in the complete temperature range with a resolution of 0.02°C.

Sensor packaging design and performance test

IR temperature sensor

The IR temperature sensor was provided in a compact, sealed package. The sensor has been mounted facing the skin, and during use there must be a free sight between the IR sensor and the skin. The field of view (FOV) for the sensor is large, ± 50 degrees until 50 % levels, and any material within this opening will affect the measurement significantly but also materials outside the 50% FOV will have an effect. The IR sensor is programmed with emissivity 1, while for skin it is approximately 0.98. Hence the measurements will be too low unless it is corrected for in the result. (Measuring 30°C will typically be a target temperature of 31.5.)

Humidity and temperature sensor.

Unlike many other physical quantities humidity measurements require a physical opening in the package for water transport to and from the sensor. Hence, for sensor packaging evaluation two different package solutions were used, package type A and B.

For package A the sensor was enclosed into a pouch made from Gore-Tex Paclite to act as a membrane for moisture transport. For package B only the sensor opening of the sensor was covered with a membrane made from the same Gore-Tex Paclite material. It was glued directly onto the

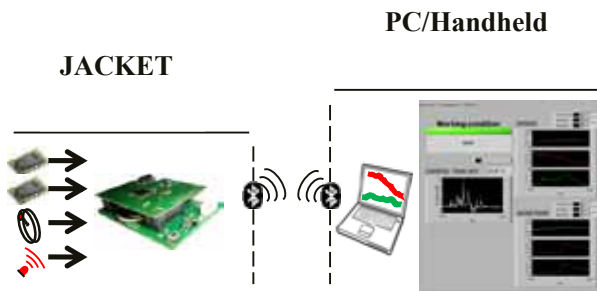


Figure 2 Overview of the demonstrator with sensors, PCB and computer with LabView program.



Figure 3 Location of PCB, sensors and LED.

sensor with a low viscosity adhesive, Loctite Super Glue liquid (cured at room temperature), see Figure 4. For easy assembly onto the demonstrator jacket, a piece of Velcro was attached with EPO-TEK 302-3M (cured at 65 °C) to the backside of the packages. The cabling was attached with standard lead free solder.

To investigate the performance of the packaged sensors, they were mounted in the prototype jacket. Package A and B was assembled on the outside of the jacket together with one K-type thermocouple (for reference temperature measurements). On the inside of the sleeve another identical package A was mounted. The jacket was subjected to controlled environmental exposure in a climate chamber (Termaks KBP 6395 F). Humidity and temperature were varied to study the response and accuracy of the sensors. A humidity ramp (Humidity (% RH at 22 °C): 30 → 50 → 70) at constant temperature followed by a temperature ramp (Temperature (°C at 70 % RH): 22 → 30 → 40 → 50) at constant humidity were performed.

Performance of temperature and humidity sensor system

Figure 5 shows that the response time was significantly longer for package A. The reduced transient response for package A inside the sleeve compared with the identical package outside the sleeve is believed to be caused by the fabric in the close vicinity of the sensors. Both the fabric of the jacket and the membrane itself act as a moisture reservoir, cf. with a capacitor in electronics or a thermal

lump mass in a thermodynamic system. Thus, the packaging solution of the sensor must contain materials that limit the moisture absorption as much as possible in the close vicinity of the sensor. The sensor placed inside the jacket will always have a slow response due to the fabric in the jacket itself, which cannot be removed. These results were true for both the temperature and humidity measurements but were much more pronounced for the humidity readings.

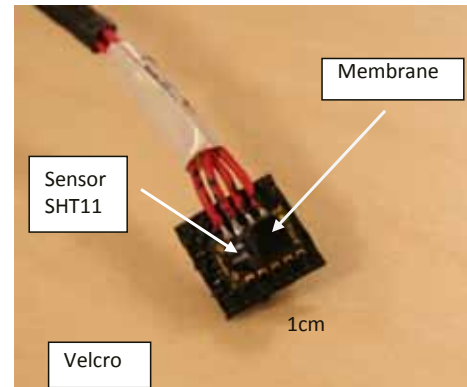


Figure 4 Fabricated temperature and humidity sensors with Gore-Tex Paclite membrane.

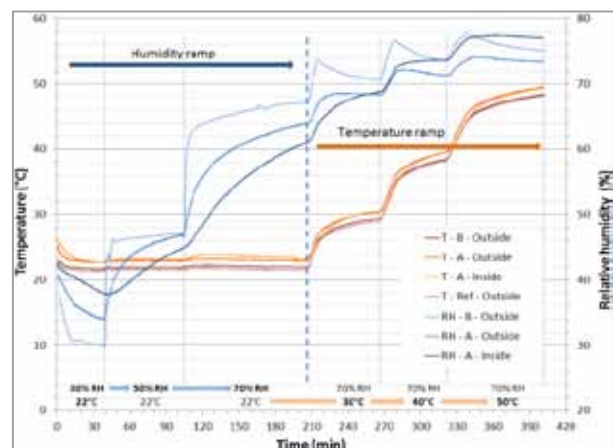


Figure 5 Humidity ramp followed by a temperature ramp. RH – Relative humidity, T – Temperature, A – Package A, B – Package B, Ref. Reference sensor.

Test of demonstrator in work physiology laboratory

The demonstrator jacket was tested in the work physiology laboratory at SINTEF using reference temperature sensors in warm (+22 °C / 50 % relative humidity (RH)) and cold (-5 °C) climatic chambers. One female test subject (37 years, 168 cm, 61 kg) volunteered for the pilot test. The test person was fitted with thermistors, heart rate recorder and then dressed with thin woolen underwear (Janus Pro Antiflame rib sweater and pants). The sleeve of the jacket was used also during the resting period. After rest for 20 minutes in the preparation room, the subject dressed with the Wenaas demonstrator

jacket and Wenaas uninsulated trousers and moved into the cold climatic chamber. A picture of the test person in the climate chamber is given in Figure 6. The protocol used included hard work to increase metabolic heat production and rest in both cold and warm environment. An overview of the protocol is given in Table 1. The protocol was chosen to simulate a petroleum workers condition during parts of a day, varying between in-house (22 °C) and outside (-5 °C) assignments.

Reference skin temperatures (YSI 700, Yellow Spring Instrument, USA , accuracy 0.15 °C) was measured on 13 sites: rectal, forehead, neck, right shoulder, left chest, finger, right abdomen, back, wrist, right anterior thigh, left posterior thigh, right shin, right calf and hand. The ambient temperature and humidity in the climate chamber was measured with a reference sensor (SHT11 from Sensiron) and sent wireless to a computer.

Table 1 Protocol used in test of demonstrator in work physiology laboratory in Sintef. Environment settings: cold chamber - 5 °C, warm chamber 22°C , 50 % RH.

Description	Comment
Rest in cold chamber	
Activity in cold chamber (walk on treadmill)	60-70 % of HR max
Rest in cold chamber	Open jacket
Transfer to warm chamber (22°C)	
Rest in warm chamber	
Activity in warm chamber (walk on treadmill)	60-70 % of HR max
Transfer to cold chamber	
Rest in cold chamber	Open jacket
Jacket left in chamber	

Subjective evaluation of thermal sensation and comfort was assessed using the scales described by Nielsen et al. [7]. The evaluation on thermal comfort included the body, feet, head and neck. The evaluation also included questions on shivering/sweating, thermal sensation of the skin, the ambient temperature and the overall thermal comfort of the test subject.



Figure 6 Test object during activity period in the cold environment (-5 °C).

The heart rate was recorded continuously using a Polar Sports Tester (Polar Electro, Finland) and was used to measure the exercise intensity, which was set to be 60 - 70 % of the maximum heart rate (HR Max) of the test subject (170 beats per minute (bpm)). The test subject walked on a treadmill. At the first exercise interval, the exercise intensity was 5.5 km/h with the slope angle of 10.5 %, after 15 min, the slope angle was adjusted to 13

%, at the second exercise interval; the exercise intensity was 5.6 km/h with the slope angle of 13 %.

RESULTS AND DISCUSSION

Reference temperature and thermal comfort

Figure 7 shows the measured reference skin and core temperature for the test subject. The reference skin temperatures dropped when the test person rested in cold temperature. This was particularly evident for the measurement on the finger. When the test subject started activity the metabolic heat production increased and as a result the skin temperatures also increased. Reference skin temperatures was further increased when the test person moved from cold (-5 °C) to warm (22 °C) environment.

Figure 8 shows the core temperature and the heart rate for the test subject. The core temperature increased with activity and correlated well with the increase in heart rate. Core temperature increased by 0.9 °C during the activity periods, and then dropped during the rest periods. The moderate increase in core temperature reflected the moderate increase in work intensity and heat production during the test.

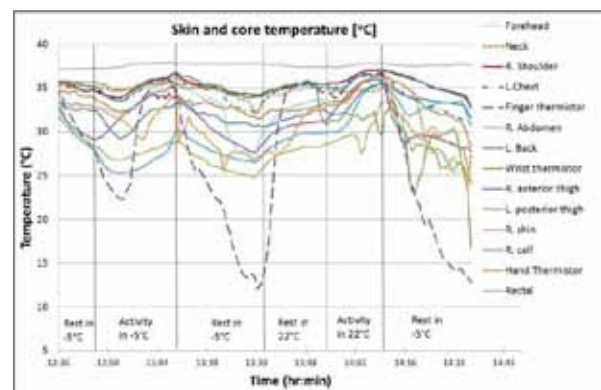


Figure 7 Measured skin and core temperature during the test sequence.

The overall perceived thermal comfort of the body and hands correlated well with the measured temperatures of the body (Figure 9 and Figure 10). During the work period in the cold (-5 °C), the perceived thermal comfort of the body was neutral, while the hand was "cool". During the activity period in the warm environment the subjects perceived thermal comfort was "hot".

The test demonstrated that the protocol was suited to simulate activity where the subjects experiences both cold and warm periods. The reference temperature of the finger dropped below 15 °C for about 10 minutes. This is below the limit which is closely related to severe loss of manual performance [5, 10].

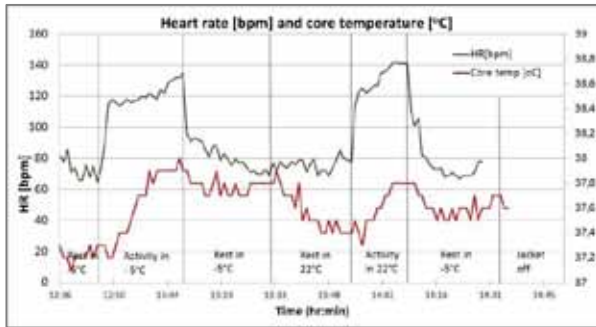


Figure 8 Heart rate during test in beats per minute (left axis) and core temperature in °C (right axis). Maximum heart rate for test subject is 170 bpm.

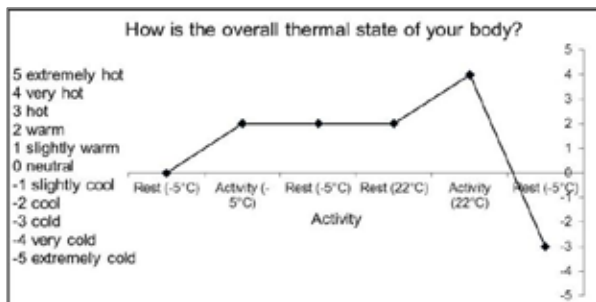


Figure 9 Thermal state of the body.

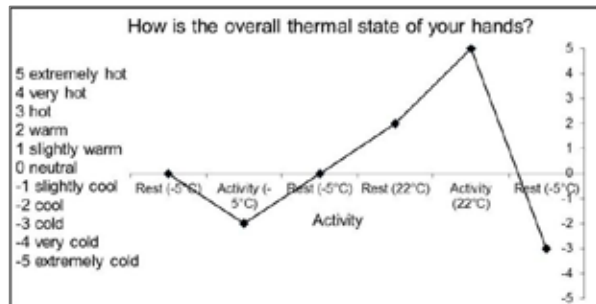


Figure 10 Thermal state of the hand.

Comparing demonstrator with environment data

Figure 11 shows the inside and outside jacket temperature measurements together with the environment temperature during the test sequence. The data have been filtered and averaged with a running average of 10 samples. The ambient temperature in cold environment was -5°C and in warm 22°C. The data show that in cold environment the outside jacket sensor measured a higher temperature than the environment, probably affected by the warmer jacket/body. In the warm chamber the outside jacket sensor measure a higher temperature than the ambient condition, probably affected by the heat flux from the warmer body. At the end of the test the jacket was left in the cold chamber, and the temperature then decreased. This suggests that the outside jacket temperature sensor was affected by the jacket/body temperature.

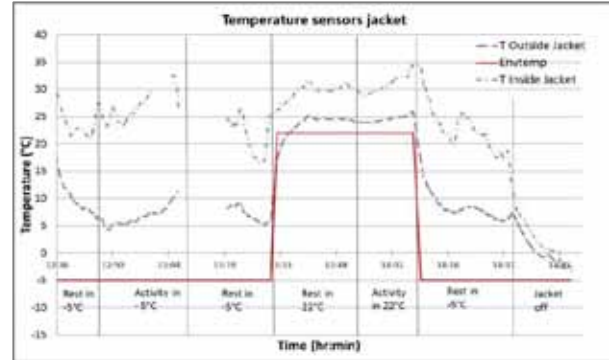


Figure 11 Temperature measurements inside and outside jacket.

The measured relative humidity (RH) outside the jacket and the environment humidity are compared in Figure 12. In the cold chamber there were no regulation of humidity, but it was measured to be about 7 %. In the heat chamber it was regulated to 50 %. The humidity outside the jacket correlated well with the environment humidity, but was somewhat higher in the cold chamber where the humidity was low. The spike in humidity outside the jacket at start of test in heat chamber (13:31) was due to temporary condensation on the sensor surface when the test subject moved from the cold to the heat chamber.

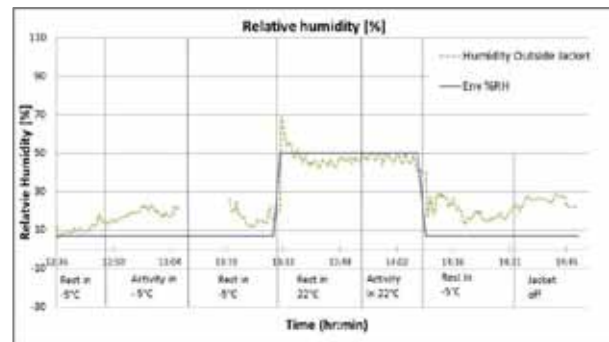


Figure 12 Measured RH outside the jacket and the environment RH during the test sequence.

Comparing demonstrator with reference data

In Figure 13 the demonstrator temperatures with IR sensor data and the temperature inside the jacket together with the finger reference thermistor are plotted. The IR temperature data have been filtered and averaged with a running average of 30 samples. The data have also been corrected for error in the emissivity.

The demonstrator temperature sensors showed the same fluctuation trend as the finger reference sensor (T_{fi}). However the absolute level of the IR sensor was somewhat higher than the T_{fi} reference sensor in the cold periods and lower in the warm periods (Figure 13). The difference observed in temperature between the IR sensor and the T_{fi} sensor can be explained by two factors. First, the position of the sensors was not the same and IR sensor was insulated by the jacket.

The fluctuation in finger temperature can be explained by the physiological process of finger vasodilation and -constriction. This is the way the body controls the rate of heat exchange with the environment by regulation of the skin blood flow. Sweat production (evaporative heat loss) or shivering (heat production) sets in at larger deviations in body temperature. This is a rapid response induced either by changes in the ambient temperature or the heat generated by the body. These temperature fluctuations will be less at the location of the IR sensor compared to the finger. However, the IR sensor was still able to detect the fluctuations in blood flow at the wrist level. Secondly, some of the difference in temperature between the IR and T_{fi} may also be explained by the large FOV of the IR sensor and can be improved in an enhanced demonstrator design by forcing the position of the IR sensor to be close to the skin. From the IR sensor results there was a good indication of the regulation of skin blood flow. There was a clear relationship between T_{fi} and IR sensor measurements that can be used in the future as a tool to give early warnings of critical temperature limits for manual performance.

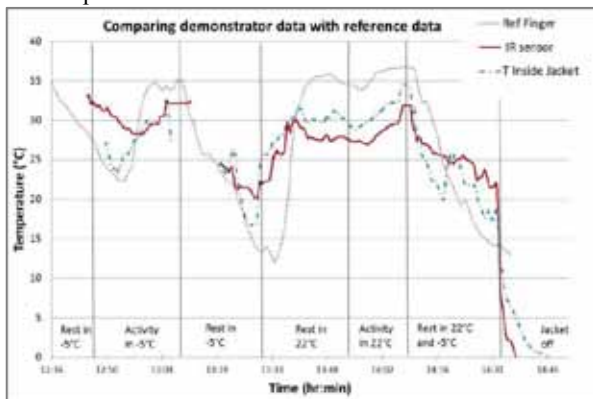


Figure 13 Temperature profile for demonstrator and reference sensors.

Together with information about the environmental data and the insulation value of the clothing, algorithms can be developed that will provide more exact information about critical limits for work in the cold than the current WCI and ISO 11079 is able to provide.

The relative humidity outside and inside the jacket, together with the heart rate, are plotted in Figure 14. This figure together with a subjective evaluation of sweat (Figure 15) showed that the humidity sensor inside the jacket can be used as an indicator for sweat.

The start of sweating during activity was easy to measure, the humidity increased fast. This was true in both chambers. Between the two activities phases the humidity inside the jacket decreased. However it was higher than the environment humidity, even though the jacket was opened up.

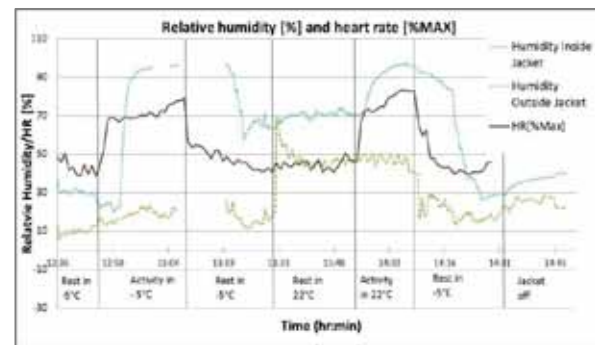


Figure 14 Relative humidity outside and inside the jacket together with the heart rate (% of test subjects maximum heart rate).

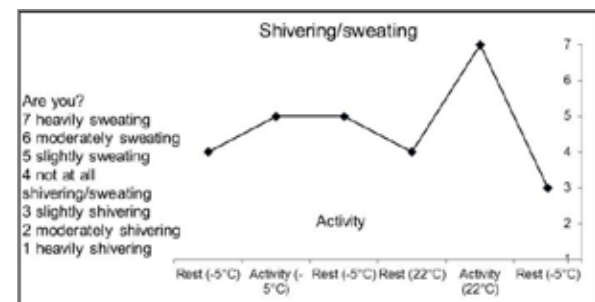


Figure 15 Test persons subjective evaluation of shivering/sweating.

FUTURE WORK

This demonstrator was made to evaluate if this particular sensor setup could provide information about ambient conditions and physiological parameters in a way that enhances the safety of workers, and improvements are necessary to enable more excessive testing and field testing. The IR sensor should be fastening tight relative to the skin so that the FOV of the sensor is “free”. The demonstrator has to be more resistance to wear, movements and short circuits, and the sensor points should be fixed. The temperature sensor outside the jacket was clearly under the influence of the temperature from the jacket/body. If the purpose of this sensor should be to measure the ambient temperature this sensors must be isolated from the jacket. The demonstrator should be validated for use at different ambient temperatures used in the pilot test and at different work intensities.

CONCLUSION

This study showed that sensors can be integrated in clothing that can provide valuable information about ambient conditions and skin temperatures of a worker during hard work and rest in cold and warm environment without disturbing the user. The demonstrator provided easy accessible information about the thermal conditions at the site of the worker and local cooling effects of extremities. This information can be used in an enhanced

safety perspective, as an improved tool to advice outdoor work control for workers in cold climate. Improvements of the demonstrator is necessary to enable more accurate information; algorithms should be developed that can provide more direct assessment of cold stress. In the future, this will represent an improvement compared to existing current international standards.

ACKNOWLEDGMENTS

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Functional Warp Knitted Fabrics with Integrated Superelastic NiTi Filaments

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ABSTRACT

We report on a particular direction of currently conducted extended research on novel textiles with integrated thin metallic filaments made of an intermetallic shape memory NiTi alloy exhibiting functional behavior such as superelastic deformation up to 10% and thermally induced shape memory effect. Within this research direction we focus on development of single and multi-layered warp knitted fabrics directionally reinforced with superelastic NiTi filaments. First, we describe expected properties of such novel structures and their potential applications. Second, we present functional thermomechanical behavior of applied superelastic NiTi filaments. Third, we address questions related to design and fabrication of warp knitted fabrics with integrated NiTi filaments. Then, we describe experimental methods applied on novel functional textiles in order to evaluate their functional properties. Finally, we present and discuss results of experiments carried out on these novel functional textiles.

Keywords

Warp knitting, phase change materials, shape memory alloys, superelasticity, martensitic transformation, Nitinol

INTRODUCTION

The use of shape memory materials represents one of several approaches which are being adopted in development of smart textiles exhibiting additional functional properties and/or outstanding structural behavior [6]. Within this approach, shape memory polymers (SMP) are mostly being used as their structural and other comfort properties (hand, air permeability, surface roughness, drape, etc.) are similar to those of conventional textile materials [6]. In contrast, the use of shape memory alloys (SMA) in smart textiles has been reported in much smaller extend [1, 2] though they outperform SMP in many aspects such as strength, thermal and cyclic properties' stability, thermally induced recovery stresses etc. [5]. In addition, incorporation of SMA into textiles has been mostly limited to their ex-post integration in the form of coils or ribbons into conventional textiles [6]. However, development of

hybrid SMA textiles produced by direct textile processing of SMA filaments has not been addressed extensively.

In this paper, we deal with design, fabrication and mechanical properties evaluation of single and architected multi-layered warp knitted fabrics made of conventional textile materials and incorporating straight superelastic SMA filaments in the weft direction. Such fabric has been conceived in order to project the functional properties of SMA filaments onto a plain structure and combine these properties with structural behavior of conventional weft knitted fabrics. Hence, in such a design, weft knitted structure provides not only structural support for SMA filaments but also mechanical properties that are responsible for macroscopic behavior when loading direction is not parallel to SMA filaments orientation. Moreover, we extend such design to multi-layered structures comprising several single weft knitted fabrics stacked and fixed one to each other at different mutually rotated NiTi filaments orientations (i.e. an architected structure) so as to provide a desired degree of anisotropy of functional properties inherited from SMA filaments.

The single and architected multi-layered warp knitted fabrics might be used for applications which would benefit from the following functional properties are required:

- Functional properties of superelastic SMA wires
 - Superelasticity (see below)
 - High strength (~2 GPa)
 - High passive damping capacity
- Customized directional distribution of functional properties

FUNCTIONAL BEHAVIOUR OF THIN SUPERELASTIC NiTi FILAMENTS

Shape memory alloys belong to the class of smart materials whose functional properties are derived from reversible solid state thermoelastic martensitic transformation [7]. They exhibit functional properties such as the temperature driven one- and two-way memory effect, superelastic deformation (up to 10% strain), high damping capacity and high work output upon a thermal excitation. Among these alloys, NiTi is currently most popular SMA and is being commercially used mainly in the biomedical field as NiTi has been proven biocompatible [3]. Besides, NiTi alloy shows by far the largest energy density as it exhibits

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simultaneously large recoverable strains and stresses during thermal actuation.

In this work, we selected thin superelastic NiTi filaments of diameter 75 microns as the material providing the functional properties to be projected onto the weft knitted textiles. We purchased these filaments from Fort Wayne Metals Ltd. [4], providing them under product name NiTi #1. The filaments were delivered in so called straight-annealed state i.e. they exhibited functional properties in as delivered state and no further heat treatment had to be applied. The selected NiTi alloy is called superelastic as the stable microstructure phase at room temperature is cubic austenite, which can be transformed into monoclinic martensite, stable at lower temperatures, by applying external loads. Such so called stress induced martensitic transformation gives rise to nonlinear hysteretic tensile behavior shown in Fig. 1, which depicts all peculiar features of superelastic NiTi filaments such as large recoverable strain (8%), occurrence of plateaus, different Young module of austenite (~50 GPa) and martensite (~20 GPa), stress hysteresis and strong thermomechanical coupling shifting the transformation plateaus by 5.5 MPa per degree of temperature change. Besides these functional properties, the filaments shows excellent mechanical properties such as the ultimate tensile strength of 1.8 GPa and yield stress for plasticity of 1.6 GPa [5].

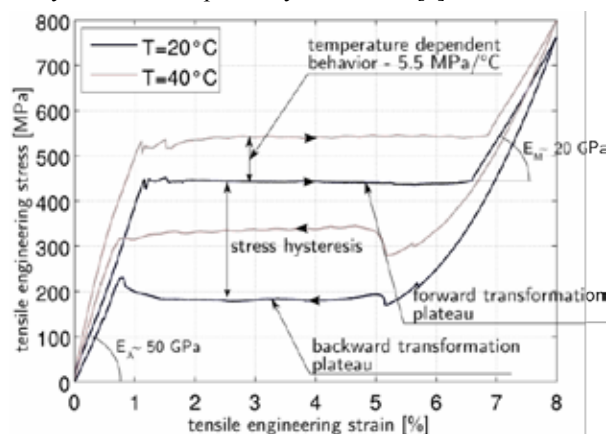


Fig. 1 Tensile behavior of superelastic NiTi filaments of diameter 0.075 mm at two temperatures.

DESIGN AND MANUFACTURE OF FUNCTIONAL WARP KNITTED FABRICS

Functional warp knitted fabrics are based on warp knitted closed fabrics with wale density of 500 m^{-1} and course density of 800 m^{-1} made of a polyester multifilament yarn of 38 tex. Firstly, a referential sample of such a fabric was manufactured. In this paper, the referential sample is denoted as PES. Secondly, the functional warp knitted fabric was manufactured by inserting thermoplastics coated NiTi filaments in course direction every 5th course during warp knitting. The thermoplastic coating of NiTi filaments was applied in order to fix NiTi filaments in the fabric. The fixation was realized after knitting through application of

heat and pressure on the fabric, which lead to gluing the NiTi filaments to polyester yarns through the melted thermoplastic coating. Fig. 2 shows structure of a manufactured functional warp knitted fabric. In this paper, the functional warp knitted fabric sample is referred to as NiTi+PES.

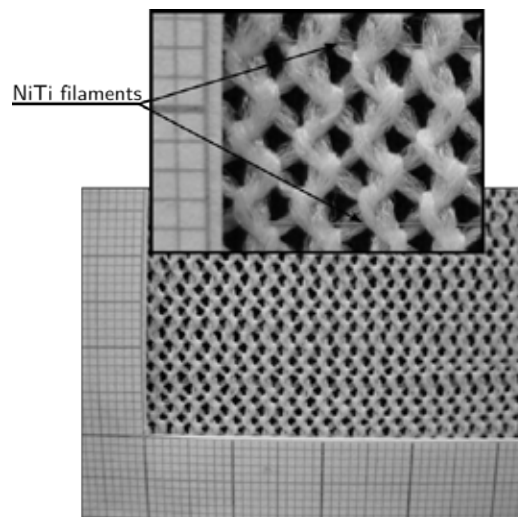


Fig. 2 Photographs of a functional warp knitted fabric sample referred to as NiTi+PES.

EXPERIMENTAL CHARACTERIZATION OF MECHANICAL PROPERTIES OF FUNCTIONAL WARP KNITTED FABRICS

We evaluated the mechanical functional behavior of studied warp knitted fabrics using two experimental methods. First, we applied simple uniaxial tensile tests at room temperature to investigate the mechanical behavior under uniaxial loads. During a tensile test, we recorded tensile force, displacement of grips as well as the displacement field on the surface of the fabric using a digital image correlation (DIC) technique described in the next paragraph. Second, we employed dedicated in-house made bulge test equipment with the aperture diameter of 100 mm (see the scheme in Fig. 3 and photograph in Fig. 4) to investigate the mechanical behavior under complex loads. When applying the bulge test, the specimen is placed over a circular die with a spherical aperture and clamped around the perimeter. Then, an increasing pressure is applied to inner side of the diaphragm, causing the specimen to bulge through the aperture. During a bulge test, we recorded evolution of inner pressure, stroke of the pole of the deformed specimen and the displacement field on the surface of the fabric using the DIC technique described below. As studied textiles are porous, they were underlaid with a thin elastomeric membrane. Therefore, the bulge test in such a configuration provides data somehow distorted due to the presence of the membrane. However, the stiffness of the membrane is extremely low as seen in Fig. 5 comparing data measured on the membrane and referential warp knitted fabric with the underlying membrane. It can be seen that the stiffness of the

membrane is far lower than the one of the referential warp knitted fabric, which itself is much softer than functional warp knitted fabric as will be seen in the following text. Therefore, the distorting effect of the membrane on experimental data providing by the bulge tester is neglected.

Both the methods were applied at a quasistatic loading regime and in conjunction with the use of the digital image correlation (DIC) technique allowing for the measure of a displacement field at the surface of fabrics. The technique consists of painting a speckle pattern (see Fig. 4) on the fabric and recording the photographs of the deformed pattern during mechanical loading of the fabric. The displacement field is then computed by correlating pattern photographs recorded at different loading steps.

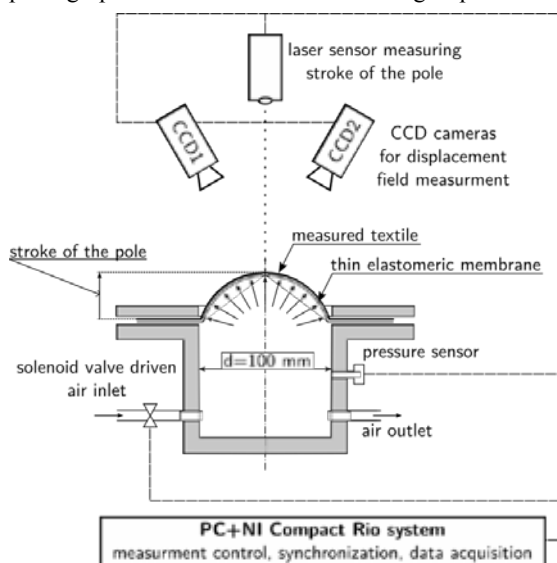


Fig. 3 Schematic representation of the bulge tester showing its main components .

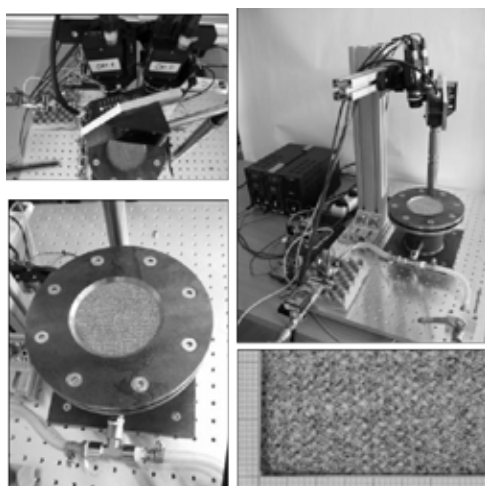


Fig. 4 Photographs of the bulge tester and details of a specimen of a tested textile with painted spackle pattern for digital image correlation.

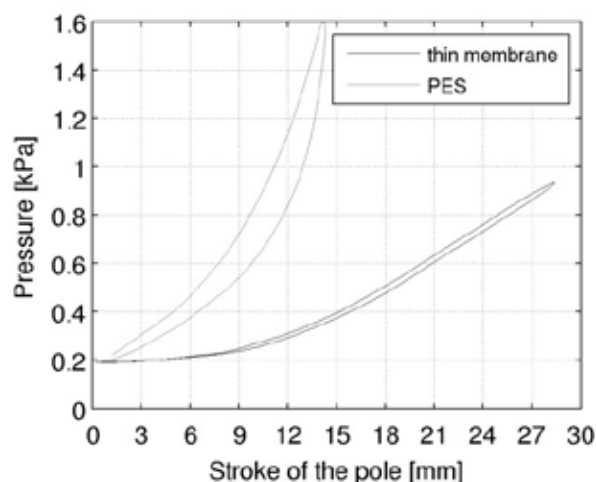


Fig. 5 Bulge test results obtained on underlying thin membrane and polyester weft knitted fabric (PES) underlaid with the thin membrane.

EXPERIMENTAL RESULTS PRESENTATION AND DISCUSSION

Mechanical behavior under uniaxial tensile loads

A referential PES sample free of NiTi filaments and a functional warp knitted fabric sample denoted NiTi+PES containing 26 NiTi filaments were subjected to uniaxial stroke controlled loading/unloading ramps in the course direction i.e. along the direction of the NiTi filaments. Fig. 6 displaying related experimental tensile curves shows clearly that tensile responses of both the samples differ qualitatively as well as quantitatively.

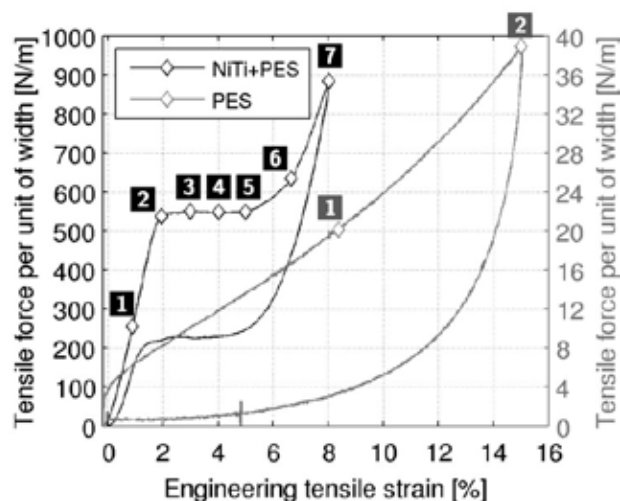


Fig. 6 Experimental tensile curves related to uniaxial stroke controlled loading/unloading ramps in course direction i.e. along the direction of NiTi filaments in the case of NiTi+PES sample. NiTi+PES sample contained 26 NiTi filaments. PES denotes referential sample free of NiTi filaments. Numbered markers represent instants at which spatial displacement fields were measured.

First, the tensile response of NiTi+PES sample is completely driven by tensile properties of NiTi samples (compare the tensile curve NiTi+PES in Fig. 6 with that in Fig. 1); whereas, the tensile response of the PES sample corresponds to the one typically observed on conventional knitted fabrics. Moreover, not only is the macroscopic tensile response of the NiTi+PES sample inherited from the tensile behavior of NiTi filaments but their presence also gives rise to the phenomenon of the localized transformation deformation, which is the typical deformation mechanism active in SMAs. The appearance of localized deformation can be revealed as an inhomogeneity in spatial displacement derivative. Such an inhomogeneity was indeed measured as displayed in Fig. 7 showing displacement in the direction of the loading axis x along the sample axis of the NiTi+PES sample (see Fig. 8) at several loading instants numbered according to Fig. 6.

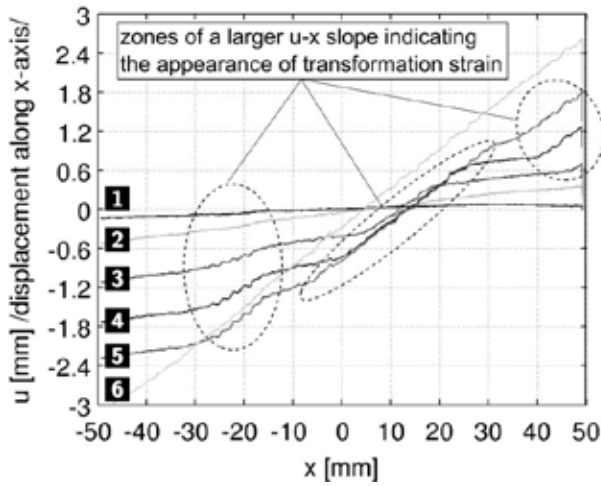


Fig. 7 Displacement in the x direction along the sample axis (see Fig. 8) of the NiTi+PES sample measured at several loading instants according to Fig. 6.

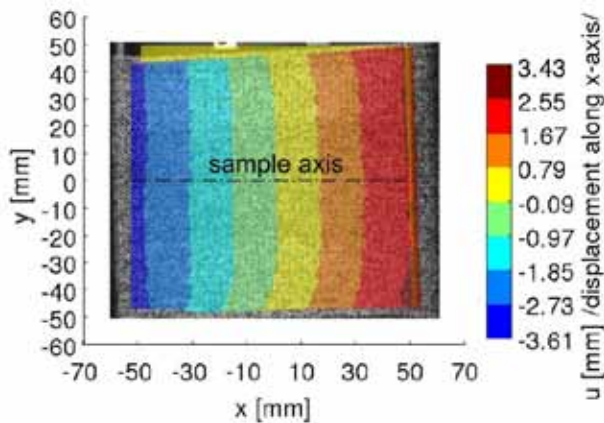


Fig. 8 Displacement field in the x direction on the surface of the NiTi+PES sample measured at loading instant 7. The sample axis denotes the line along which the displacement u is plotted in Fig. 7.

Second, tensile behavior of both the samples differs considerably in terms of stretchability and stiffness. The NiTi+PES sample displays lower stretchability, which is yet high compared to reversible deformability of common metals. On the other hand, the NiTi+PES sample shows considerably higher stiffness. The tensile force needed to stretch NiTi+PES sample to 8% is more than 80 times higher compared to the PES sample. However, NiTi filaments affect not only the deformation properties in the direction of their placement but also in the transverse direction. When comparing displacements in the direction transverse to the loading axis measured on PES and NiTi+PES samples (see Fig. 9 and Fig. 10), one can conclude that the typical transverse shrinkage commonly seen on knitted textiles is considerably suppressed by NiTi filaments.

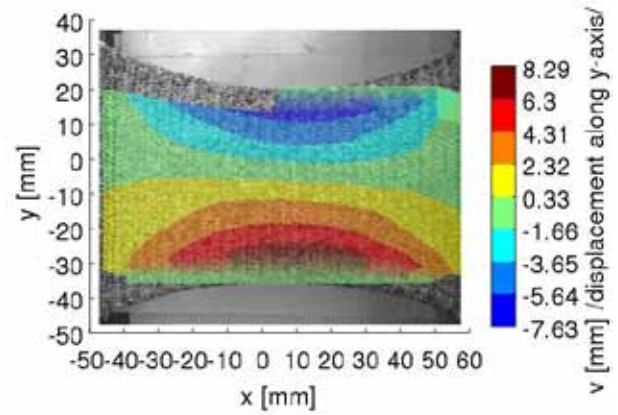


Fig. 9 Displacement field in the direction transverse to the loading axis measured on the surface of the PES sample and gathered at loading instant 2 (see Fig. 6).

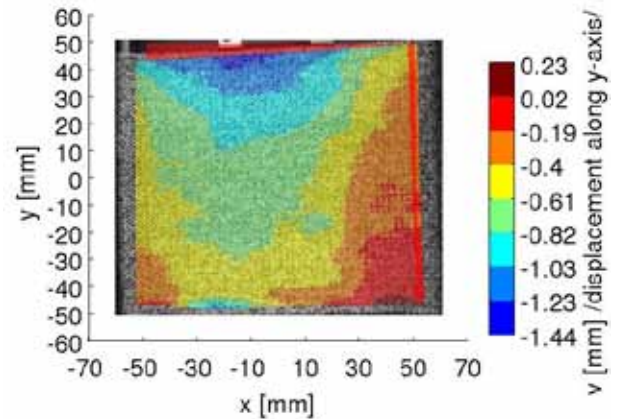


Fig. 10 Displacement field in the direction transverse to the loading axis and to the direction of the NiTi filaments placement measured on the surface of the NiTi+PES sample and gathered at loading instant 7 (see Fig. 6).

Mechanical behavior under bulging

A Referential PES sample free of NiTi filaments and two types of functional warp knitted fabric samples were subjected to bulge tests. During these tests the samples

were subjected to inner pressure loadings/unloadings in the regime of stroke of the pole controlled ramps. The first tested functional warp knitted fabric sample denoted NiTi+PES#1 represents a single layer fabric with NiTi filaments inserted in the course direction as described above. There were 16 active NiTi filaments over the aperture of diameter of 100 mm of the bulge tester. The second tested functional warp knitted fabric sample denoted NiTi+PES#2 consists of two layers of NiTi+PES#1 mutually rotated by 90° i.e. NiTi filaments were placed in two perpendicular directions.

As in the case of tensile testing, the pressure vs. the stroke of the pole characteristics of PES and NiTi+PES#1,2 differ qualitatively as well as quantitatively (see Fig. 11, Fig. 12). NiTi+PES#1,2 characteristics inherit the typical nonlinear hysteretic behavior exhibited by NiTi filaments in tension. However, the plateau indicating the appearance of the transformation is not horizontal but inclined. Supposedly, it is due to the fact that the macroscopic behavior of the fabric is determined by a superposition of NiTi filament behavior and that of polyester weft knitted structure. Moreover, it might be due to different active lengths of NiTi filaments depending on their placement over the aperture (see Fig. 13). Hence, individual NiTi filaments provide different transformation strains. Therefore, while some NiTi filaments are in the transformation stage i.e. they project their plateaus on the overall mechanical behavior of the fabric, other NiTi filaments are already in the elastic regime beyond the plateau i.e. they project linear elastic behavior on the overall mechanical behavior of the fabric.

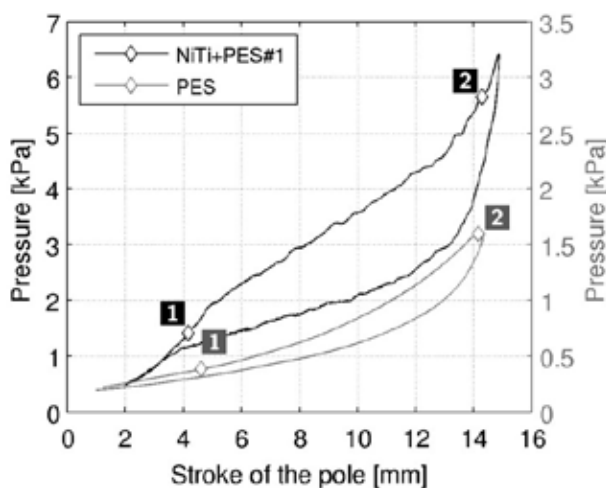


Fig. 11 Pressure vs. stroke of the pole characteristics of the referential PES sample and one layer NiTi+PES#1 sample both measured via the bulge tester.

Furthermore, NiTi+PES#1,2 show considerably higher stiffness while keeping the stretchability of PES. The pressure required to bulge the NiTi+PES#1/ NiTi+PES#2 sample to 15 mm of the stroke of the pole was nearly 6/12 times higher compared to the PES sample. Note that the

stroke of the pole of 15 mm was close to the limit of the reversible stretchability of all samples.

As expected, the NiTi+PES#2 sample containing two layers of the NiTi+PES#1 sample exhibits double of the stiffness of the NiTi+PES#1 sample (see Fig. 12).

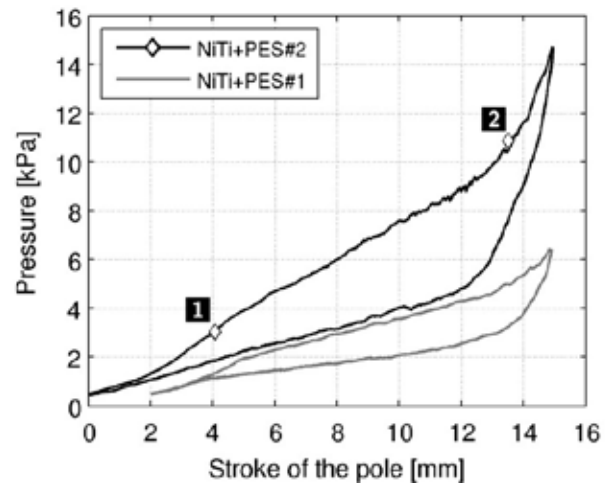


Fig. 12 Pressure vs. stroke of the pole characteristics of one layer (NiTi+PES#1) type and two layer (NiTi+PES#2) type of the functional warp knitted fabric measured via the bulge tester.

The responses of all studied samples to bulging via inner pressure differ also in terms of the shape of the characteristic cap into which textiles are deformed during a bulge test. The NiTi+PES#1 sample exhibits strongly inhomogeneous, non-axisymmetric deformation field at low applied pressures as illustrated in Fig. 13. The waviness of the deformation field is supposedly driven by unidirectional distribution of NiTi filaments. On the other hand, the PES sample as well as the NiTi+PES#2 sample show homogeneous axisymmetric deformation field at low applied pressures (see Fig. 14 and Fig. 15). Hence, it can be concluded that putting two differently oriented NiTi+PES samples over each other is sufficient to homogenize the deformation induced by applied inner pressure.

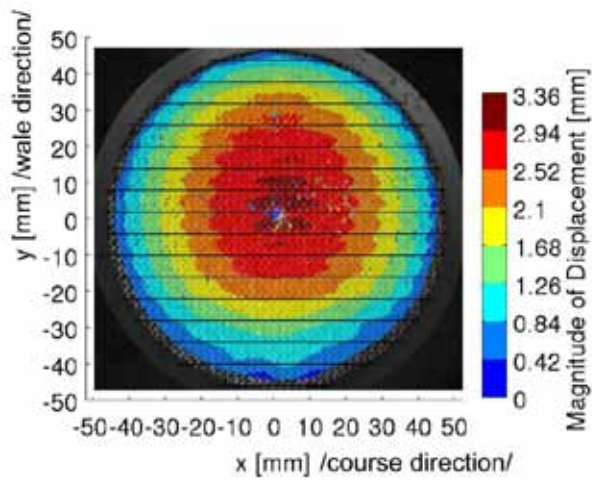


Fig. 13 Magnitude of displacement of NiTi+PES#1 sample at loading instant 1 (see Fig. 11) with indicated positions of NiTi filaments.

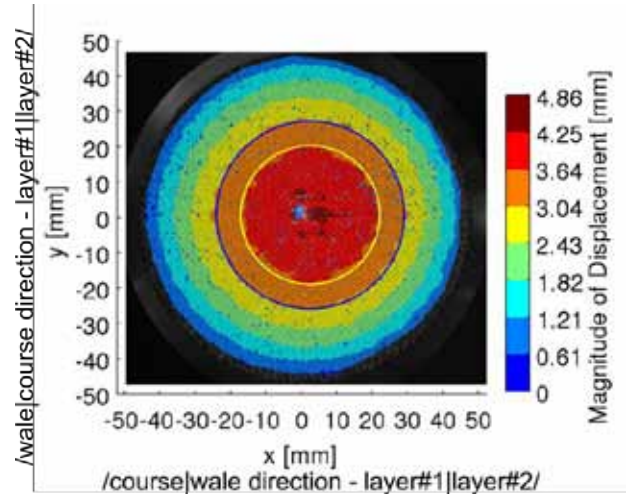


Fig. 15 Magnitude of displacement of NiTi+PES#2 sample at loading instant 1 (see Fig. 12) with indicated circular isolines.

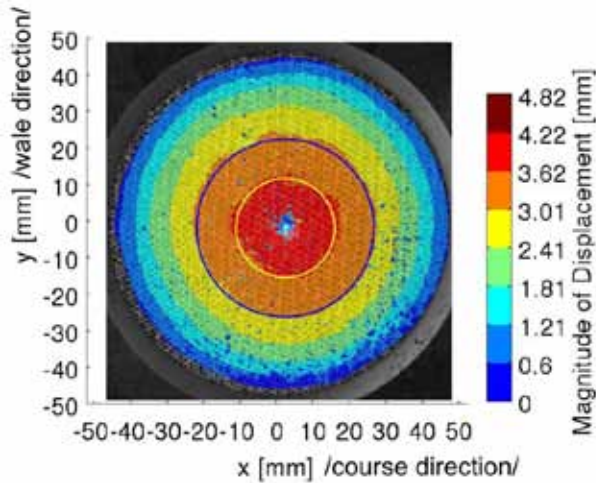


Fig. 14 Magnitude of displacement of PES sample at loading instant 1 (see Fig. 11) with indicated circular isolines.

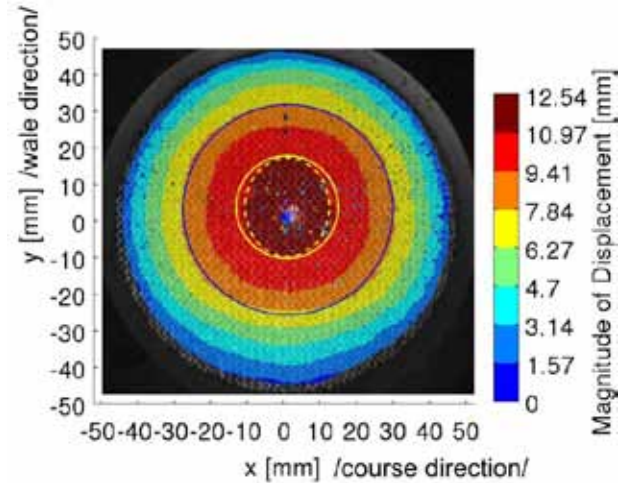


Fig. 16 Magnitude of displacement of NiTi+PES#1 sample at loading instant 2 (see Fig. 11) with indicated isolines and the asymmetry of the isoline at vicinity of the pole.

With increasing applied pressure the deformation field of the NiTi+PES#1 sample tends to homogenize (Fig. 16). Moreover, higher applied pressures make the deformation of the NiTi+PES#1 sample and PES sample anisotropic (see elliptical isolines in Fig. 16 and Fig. 17). Supposedly, such an anisotropy of the NiTi+PES#1 sample is due to the structural anisotropy of the weft knitted pattern and not by the presence of integrated NiTi filaments as the isolines of both the samples exhibit the same elliptical shapes with the same spatial orientation. On the other hand, the NiTi+PES#2 sample exhibits homogeneous isotropic deformation field at all applied pressures (see circular isolines in Fig. 15 and Fig. 18.) Therefore, we might conclude that an evenly oriented distribution of NiTi filaments makes the bulge deformation isotropic regardless the structural anisotropy of the knitted fabric.

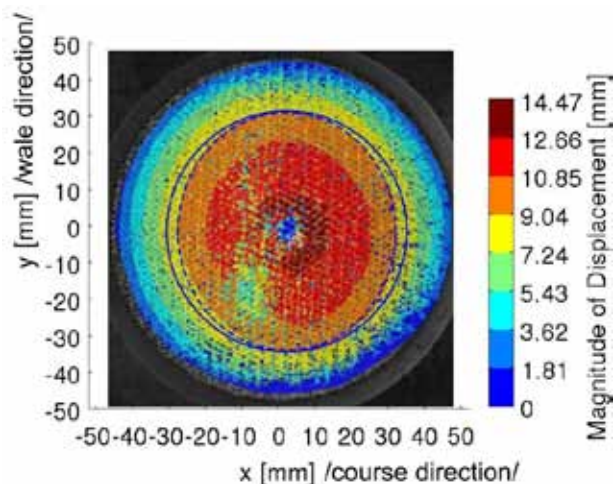


Fig. 17 Magnitude of displacement of PES sample at loading instant 2 (see Fig. 11) with an indicated isoline and its asymmetry.

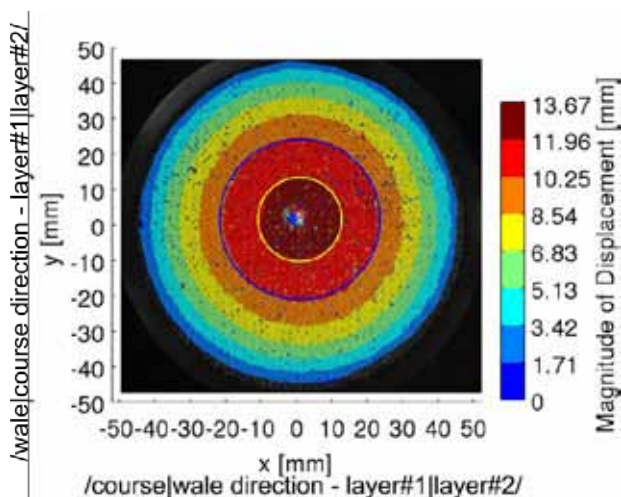


Fig. 18 Magnitude of displacement of NiTi+PES#2 sample at loading instant 2 (see Fig. 12) with indicated circular isolines.

CONCLUSIONS

We designed and manufactured novel functional weft knitted fabrics with integrated superelastic thin NiTi filaments. Their mechanical behavior was analyzed using tensile and bulge tests. We analyzed the mechanical behavior of referential polyester PES weft knitted fabrics free of NiTi filaments, a single layer of the functional weft knitted fabrics and two transversely oriented layers of the functional weft knitted fabric. As outcome of experiments, we can summarize the mechanical properties of the functional weft knitted fabric /FWKF/ and the effect of NiTi filaments integration as follows:

- FWKF inherits the nonlinear hysteretic mechanical behavior from the behavior of integrated NiTi filaments.
- FWKF exhibits much larger tensile stiffness and sustains substantially larger tensile forces compared to the referential sample free of NiTi filaments.
- The tensile stretchability of FWKF is twice as less as that of the referential sample free of NiTi filaments.
- The deformation behavior of FWKF under cyclic loadings is more stable and reversible compared to the referential sample free of NiTi filaments.
- FWKF shows considerably higher stiffness at bulge tests in comparison to the referential sample free of NiTi filaments while keeping the stretchability of the referential sample.
- One can suppress the structural anisotropy of the weft knitted pattern by combining several layers of FWKF with different NiTi filaments orientation.

ACKNOWLEDGMENTS

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Knitted Wearable Stretch Sensor for Breathing Monitoring Application

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ABSTRACT

Wearable technologies have been rapidly growing during the last decade. One of the most developed applications is the physiological and medical evaluation by using textile based sensors and electrodes. Sensors integrated into such a system are expected to be able to support the monitoring of personal activity during daily life and ensure the early detection of abnormal conditions such as sleep apnea which is a sleeping disorder phenomenon. Complete garment knitting is a one-step process, which enables to integrate the textile based sensor into a garment directly in the knitting process. The objective with this project was to design a weft knitted stretch sensor of different conductive yarns and structures. The performance of the sensors was evaluated by measuring the electrical resistance changes in the knitted structure as a function of elongation with a self-built cyclic tester. In addition, a prototype garment made by flat knitting machine has been made in order to evaluate the sensor performance as a breathing rate indicator.

Keywords

Medical textiles, Seamless knitting, Complete garment, Conductive yarns, Stretch sensor

INTRODUCTION

During the past few years many successful attempts have been made to achieve a sustainable and functional combination between textile and sensors to make a wearable health monitoring system for patients [9]. In these attempts a certain interest has been diverted towards measuring the breathing rate of human beings whether they are patients with sleep disorders, athletes or even children who need special care outside the institutions of medical treatment.

In the last decade smart textiles are associated and have been working with healthcare to incorporate some smart techniques in this field. Attempts have been made by using certain sensors with conductive polymer or optical fibers to measure physiological signals such as temperature, ECG and breathing in a human body [1][2]. For this purpose different sensors made out of textile have been developed such as gloves for hand movement, shirts for measuring heart rate [5]. Knitted stretch sensors are among them which can be used to monitor the breathing rate of a human being. Early sensors used for breathing monitoring were normally biomedical sensors such as in LifeShirt and Smart Shirt which caused inconvenience in wearing [9]. Similar past work also include the use of piezoresistive sensors along with fabric electrodes for firemen under the European project "Proetex" [8]. The stretch sensors made from weft knitting have the advantage of being stretchable and comfortable to wear and at the same time are washable. The one-step process used in knitting can lead to seamless garments and increase productivity [3]. There are many advantages of making a product by seamless knitting which in other words is also known as the one step-process for knitting. The first and foremost advantage of doing a one-step process is that there is no post cut process involved and post sew process is limited to minimum [3]. The flatbed knitting machine allows the process-ability of fibers which are stiff, brittle or conductive such as Bekinox, Shieldex etc. which can cause buildup of static charges in the machine. These fibers also require special low tension setting to minimize the breakage in the yarn. The ability to make complicated structures in one single process using computer aided designs and with consistent quality are advantages of using a flat-bed knitting machine for this purpose. All of this and it also helps in being eco-friendly by less wastage of material. The garment made by knitting is certainly comfortable, soft and body fit [7]. The structure recovery compared to weaving [3]. The knitting machine used for the purpose is Stoll CMS 330 TC.

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There are numerous materials and knitting structures which can be used for stretch sensors. In this paper, section 2 illustrates the choice of materials and structure followed with the testing method, section 3 gives the results from the tests. A prototype made by flat knitted is shown in section 4, while the results concluded in section 5.

MATERIALS AND METHODS

Sample Preparation

In this project following yarns were considered. The properties of the yarns are given in table 1 and the microscopic pictures are shown in figure 1.

Conductive yarn	Thickness	Resistance Ω /m
Copper Stainless Steel	0.05mm	105
Beakart	Nm 50/2 x 4	300
Statex Shieldex	235 34 x 2	35
Bekinox	Nm 9.1	70

Table 1: conductive yarns used in this project and their properties.

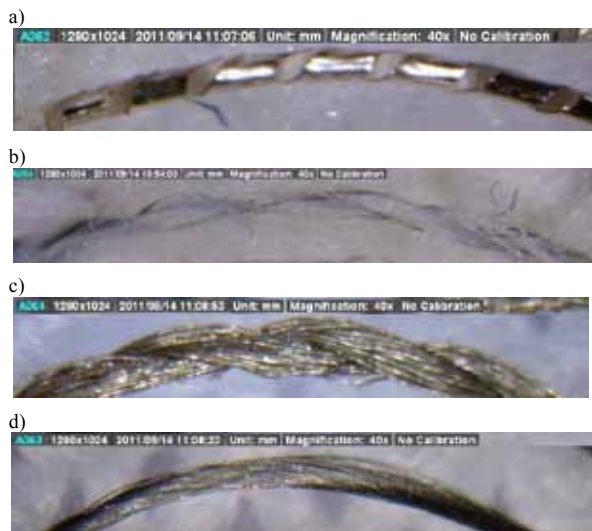


Figure 1: microscope picture of yarns used in this project. a). Cooper Stainless Steel metal yarn; b). Beakart yarn; c). Statex Shieldex yarn; d). Bekinox yarn.

Structurally these stretch sensors are in rectangular pattern having a fraction of conductive yarns in them with the longest side along the direction of knitting as shown in provided by knitting is also elastic as well as it has good elastic

Figure 2. Out of these yarns each yarn was used in making four different structures of knitting, namely: Plain Jersey (used as reference), 1 1 Rib, Interlock and Floating (fig.3). It is of importance that the structure used can show clear distinction between breathe in and breathe out and we know that the double face fabrics show less pronounced distinction [4]. For general purposes the base yarn for all the samples was PES.



Figure 2: knitted stretchable sensor made by conductive yarn.



Figure 3: microscope picture of different structures, Plain Jersey (up left); 1x1 rib (up right); Interlock (bottom left) and Floating (bottom right).

Sample Evaluation

Each yarn with the respective four structures was put to test in a self-built cyclic tester. This device was specially built by one of our lab members. The most important function of this device is to imitate the breathing pattern of human being at different rates so, it can be used to simulate breathing during sitting, standing, running and sleeping by varying the speed and the elongation of the device. This device stretches the fabric sensor sample between two arbitrary points at variable speed. The device can perform different elongation while using different speeds of up to 50mm/s for stretching.

Cyclic tester is operated together with a device called Keithley which is used to measure resistance of the sample. With the help of LabVIEWTM program, Keithley can automatically record a graph between resistance and time, by varying the time of the stretching in the cyclic tester different graphs can be obtained. Both these devices are connected together through software and the whole setup is shown in Figure 4.

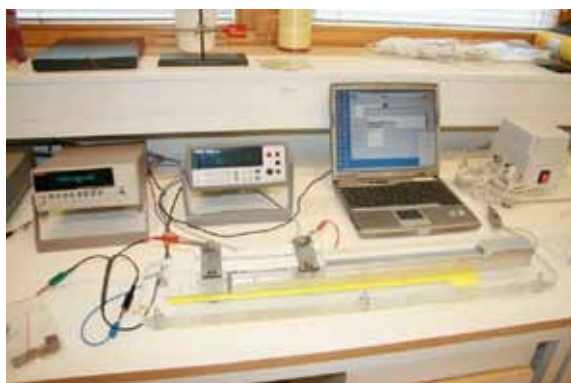


Figure 4. Cyclic tester along with attached sample sensor, Keithley and software

Sensor samples of dimension 20cm×5cm were produced for analysis. Elongation of 5% was used to imitate breathing at normal rate and stretching speed of 20mm/s was used. For each sample 20 cycles of breathing were recorded. The cycles can easily be counted from the graph once the setting for elongation is kept within 1 second. By performing this method repeatedly for all the present samples and comparing their results we were able to filter out the 2 less functional conductive yarns namely Shieldex and Bekinox and all of its structures, the reason being breathing sensor is no application for the highly conductive yarns, which makes it even more cost effective by using low cost conductive yarns with high resistance values. This was the first step to find out the conductive yarn with acceptable resistance values.

The next step was to determine the optimal structure out of the four proposed structures. The aim is to find the structure that is best suitable to be used as sensors i.e. the difference in resistance between stretching of sensor can be easily recorded and perceived. Normally two run for each sample were performed to rule out any unwanted deviations, as the knitted structure would perform differently each time it is stretched and it is difficult to predict the structural changes in knitted structure.

Prototype Garment

In complete garment production the entire garment is ready-made directly in the flat knitting machine. The different parts of the garment are knitted in the right shape and knitted together with the trimmings, pockets and other accessories. The advantages with this technique are many, no waste of material such as cut-loss in the cutting process and no expensive post-knit processes such as sewing or cutting [3] [7]. This is particularly useful when the price of the yarn is high, as often is the case with technical fibers as for example conductive yarns. All yarn in the garment comes from the same yarn cones, which enables higher quality and reduces problems with yarn from different dye lots. Due to seamless technology, the garment could both fit perfectly and be comfortable to wear. Three separate tubes are knitted, one for the body part and two for the sleeves. The sleeves and body are knitted and formed to the right shape and dimension and then joined together at the shoulder part of the garment. Because of lack of time the prototype was knitted as separate panels, cut and sewn together to a garment. The basic structure of the prototype was full rib combined with interlock structure over two feeders in the conductive parts. Intarsia technique was used to lead in the conductive yarn to form the rectangular sensors as shown in Figure 5. In particularly sensitive areas of the knitting process it is an impending risk of yarn breakage, but it is possible to reduce the speed of the machine. In this case, it was done when the conductive yarn was knitted into the garment. We believe that it is entirely possible to produce this product in one piece to gain all advantages of the complete garment technology described above.



Figure 5. Prototype garment made by flat knitting machine.

RESULT

After investigating we can say that highly conductive yarns such as Bekinox having resistance of $35 \Omega/\text{m}$ are not among the best possible yarns for breathing sensors as they can sometime give insignificant changes in resistance during inhalation and exhalation, which can be tricky to measure. Graphs conceived by PET and Beakart stretch sensors are shown in Figure 6. In all the cases the elongation is kept up to 5%, while the stretching speed is 20mm/sec. In each graph the peaks show the relaxation of the sample i.e. breathe out and lower peaks show the breath in. Complete cycle can be easily seen in the graph (fig.6). A0 (relax state) and B0 (stretched state) represent the initial resistance of the sensor while A1 (relaxed state) and B1 (stretched state) represent the final resistance of the sensor. ΔA and ΔB indicate the differences between A1 and A0, and B1 and B0. In ideal case, A0 and B0 should equal to A1 and B1 respectively ($\Delta A = \Delta B = 0$), which indicate there is no hysteresis in the sensor. However, in reality, especially when textile structure involved in, hysteresis exists in all cases [8]. Therefore, we prefer to have a sensor which has constant change in resistance against elongation ($B-A=\text{constant}$) as an alternative. As we can see from figure 5, the interlock structure perform best ($\Delta A = \Delta B$), and both 1x1rib and floating has bigger ΔB than ΔA . Another important character of sensor is the resistance in stretched state (B) should always smaller than the resistance in relaxed state (A), if so we can setup a threshold value of the sensor to record the cycles. Both interlock and floating structure fulfill this requirement, while sensor with 1x1 rib structure is beyond the requirement ($A1 > B0$).

As a conclusion, out of the four structures the most practicable structure which stands out for using in sensory garments for breathing are floating and interlock. This is because the 1x1 ribbed structures has only one set of loops going in front and back of the structure which makes the structure more elastic and loose compared the two sets of loops in interlock which are present in both sides of the fabric resulting in a dense and heavy fabric with higher elastic recovery. However, in floating structure the missed loops result in irregular results as shown in figure 6.

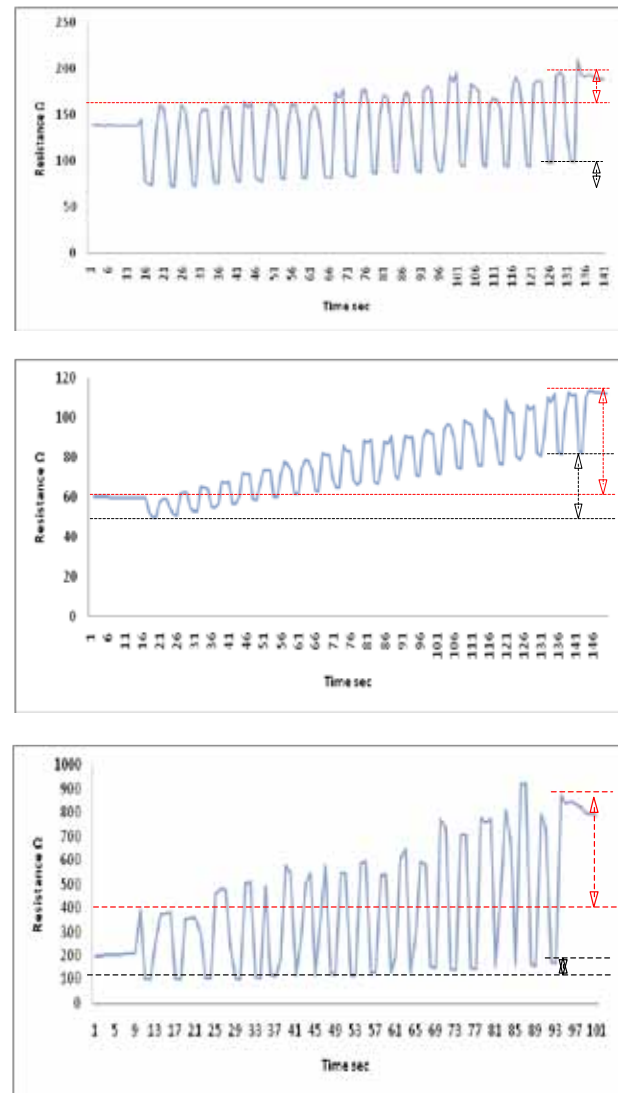


Figure 6. Resistance shown as a function of time for PET/Beakart with stretching speed of 20mm/sec, top: interlock, middle: 1x1rib, bottom: floating.

Prototype garment for breathing monitoring

Prototype garment has been utilized as a breathing monitoring shirt. The prototype garment has been tested on one health subject. During her nature breathing, the electrical signal has been recorded and the transfer through Bluetooth into a laptop, the signal collected and processed by a LabVIEW program. Signals from both sensors placed at the position of chest and abdomen were readable but not stable enough for long time monitoring, this is because the knitted loops in the garment was not compact enough to ensure a good sensitivity of both sensors. The next prototype should focus on improving the elasticity of the basic structure. This can be achieved by increasing the stitch density / decreasing the stitch length and by using Lycra yarn instead of PES as the base. Another improvement for better sensitivity is by using elastic conductive yarns.

CONCLUSION

The achievement of this work is that now we are sure that textile knitted sensors has the potential to be used for monitoring breathing of patients in their daily life without inhibiting their daily routine. This sample along with the transmitter can easily be used to record and transmit data to a computer which can compile the data and produce a graph to monitor the breath of a patient, athlete child who needs special care outside the boundaries of a medical institution. This sensor is without the transmitter is completely washable and comfortable to wear with high resiliency even after long measuring times.

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Aesthetic Replacement Strategies in Hospitals

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ABSTRACT

Hospital environments show several examples of “non-medical” facilities. Besides the intentionally aesthetic ambience, which is created through architectural design, artistic decorations, green spaces and graphic media, the shops, hairdressers and cafés stand in a non-clinical functional relief to the spaces explicitly made for clinical work. The art-based research project *Placebo: Aesthetic replacement strategies in hospitals*, examines hospital environments in relation to society, by studying the effect of non-clinical physical presence in hospital space. A particular interest is devoted to “aesthetic placebo effects”, i.e. artistic and architectural situations that have the capacity to divert attention and create a sense of pleasure (Placebo = “I shall please”). The study is made by means of explorative methods, including displayed photo-documentation, design proposals, and workplace-oriented intervention. The methodology emphasizes possibilities for letting the investigated object influence the investigatory media.

Keywords

Placebo, hospital buildings, public art, architectural design.



Figure 1. Entrance exterior, Karolinska Univ. Hospital, Stockholm. Sculpture by P O Ultvedt.

INTRODUCTION

The belief in a healing effect of the environment itself was an important part of the idea of the sanatoria. Not only the natural surroundings, offering healthy air or water, but also the (sometimes luxurious) quality as regards design and service, were thought of as having a remedying effect in themselves. In recent years, the relationship between medicine, environment and spatial organization/design has again been brought to the fore [10]. In particular, so called Evidence Based Design (EBD), a method for designing hospital environments that is based on empirical (scientific) findings, is being introduced in the planning of new and renovated hospitals [16]. EBD arguments for design proposals based on e.g. calculations of: amount of daylight inlet; risk for infections (resistant bacteria, epidemic illnesses); rate of wear-out of hospital personnel; or costs for re-organization due to old-fashioned hospital architecture. In other words, EBD aims at an extended awareness about the socio/bio/techno/-logical ambience of hospital environments. However, in each case of application, the Evidence Based Design approach has the disadvantage of focusing rigorously on certain chosen aspects – like for instance measurable daylight conditions, rates of personnel’s movement, or number of daily routine facilities that are easily accessible for the patient – while leaving other factors or overall views based on professional experience aside. The EBD research often states aesthetic/environmental aspects on the design of patient rooms and other related facilities and thus aligns with traditions in architectural and environmental research, such as studies of user functions, environmental psychology, or the more applied recent development of “green” rehabilitation [6]. In this context, it is the purpose of the *Placebo* project to initiate a complementary, and critical, examination of aspects that are explicitly related to aesthetic and artistic presence in the hospital environment.

Hospitals as reflecting places

In relation to the overall question about the extent to which the supposedly non-medical parts of the physical environment has a healing role in the hospital, one obvious aim is to investigate to what extent everyday entertaining facilities – artistic works, decorations, plants, cafes, shops, hair-dressers, magazines, etc. – are integrated into the medical situation, or experienced as something remote to medicine, pain sickness, etc. When placed in the actual

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medical environment, are these objects, facilities and art works experienced differently from what would be the case outside of the hospital?



Figure 2. Entrance waiting room, Landskrona Hospital.

Hospitals as facilities for displaying art.

Hospitals and official units of care play a major role as administrators and sites of display for public art in Sweden. Large areas of corridors and indoor wall spaces look empty and seem to cry for a permanent decoration of some kind. These interior environments are also well suited for framed works of art that can be perpetually exchanged. The handling of these spatial opportunities automatically touches upon expectations on architecture, design, and artistic interpretation and shed light on the difference between the medical/scientific and the artistic intentions, as well as the decision-making processes regarding art work commissions. Hence, it is of interest to visualize the hospital environment, not only through site-specific images of these “exhibitional” circumstances, but also by making actual proposals that address the explicitly medically related design research as well as the aesthetic practices that deal with the impact of architecture.

Theme of this paper and research project description

In this article, a set of ongoing investigations will be briefly described, investigations that are of current interest for the *Placebo* research group.¹ The set of sub-projects share a common thematic focus on “artistic presence” in the hospital environment, but also a common discussion about methodology in “artistic research”.² The research interest

¹ The research group consists of six persons: Erling Björgvinsson, MAH; Ulrika Connheim, White Architects; Anna Petersson, LTH/LU; Ann Pontén, SUS/LU; Gunnar Sandin LTH/LU; and Lars-Henrik Ståhl, LTH/LU.

² This article does not problematize the notion of “artistic research” on a meta level, however it suffices here to state that in relation to previous debates about the autonomy of this research field, we acknowledge a doxological formative ground stating that a separation between the logic of reason and the reliance of experience is not necessarily relevant, perhaps not even possible, when it

can be divided into seven sections, that also forms the content of this article:

1) *Studies of participatory environmental production:* an investigation of two existing cases of participatory aesthetic strategies in hospital environments, *SARAH Networks*, which shows a co-production strategy in and by a hospital organization in Brazil, and *1 % Love and Devotion*, showing artistic improvement initiative at a low cost at Ulleråker hospital in Sweden.

2) *Design themes in waiting rooms:* proposals made in a students’ design project for ten waiting rooms in Skåne University Hospital (SUS), Sweden. The aesthetic and thematic choice of content was discussed with the hospital personnel and the clinic’s department leaders.

3) *Installation and maintenance of public art:* a photo documentary of commissioned art and its maintenance made at SUS hospital in Malmö. A main interest is here devoted to the issue of the formal and thematic relation between art works and the surrounding physical space.

4) *Patients’ documentation of their treatment localities:* photographic activity, where patients are asked to document their immediate environment in the hospital, is encouraged as part of a questionnaire study at SUS, Lund. The negotiation of such probing methods of research and research participation is discussed.

5) *Placebo effects in life passage situations:* a photographic interest in the Malmö hospital funeral chapel, and its facilities for handling dead bodies, with the possibility to suggest adjustments of the funeral chapel’s indoor and outdoor environment.

6) *The grand hospital idea in a historical context:* a film media production about a never completed hospital in Zagreb, with an artistic interpretation of the relation between national politics and individual need for care.

7) *Research presentation in the media studied:* a contribution to the discourse about medicine and graphics, through a conference folder made in the format of comic strips.

1. RELATIONAL ART AND PARTICIPATORY DESIGN

In recent discussions within the area of contemporary visual arts regarding “social art” or “relational aesthetics”, as a paradigm for public participation and an extended direct contact with environments outside of art galleries, the importance of a more socially engaged art has been

comes to artistic decision-making. At the same instance we accept the pragmatic fact that a certain amount of situational academic circumscription of artistically grounded manoeuvres is sometimes necessary [1], [14]. We also welcome the overall tendency, in recent years, that art-based research seem to have turned from self-reflection to thematic investigation.

emphasized [2]. The facets of this essentially non-coherent area is itself highly debated and has a central position in contemporary art discourse, as well as in recent philosophical aesthetics [13]. For the more ordinary public context, such as the workplaces and common space that we find in hospitals, where art is often thought of as something framed, expensive, commissioned, and decided upon out of reach of the normal user's reality, these more experimental "relational" artistic activities still need to be pedagogically translated and introduced. Relationally oriented projects have been carried out in Sweden under official regional management: e.g. *1% Love and Devotion* [9], with the endeavor to give the hospital and its staff/patients the artistic decorations and the design improvements they themselves wish to have, and with means that can be found/developed at site.



Figure 3. *Love and Devotion*, 2003, [9].

This way, by avoiding the traditional procedure of making an interior nicer or more prestigious by buying an expensive artwork to be hung on the wall, and instead allow for artists to work in direct contact with the environment, cost-efficient solutions to the experienced aesthetic and logistic needs could be made [11].

On a larger and more institutionalized scale, the Brazilian rehabilitation hospital project *Sarah Networks* also show interesting attempts to integrate the development of the environmental and aesthetic quality of the hospital with the activities of those that work and stay there. The hospital is run by a private non-profit association, *Pionieras Sociais*, but is financed with federal means, and takes patients regardless of income level. The high grade of autonomy at these hospitals allows the design, construction and development of the hospitals' own parks of furniture and certain clinical devices. The project *Sarah Networks* also stimulates patient participation by integrating rehabilitation within the daily maintenance activities, as well as supporting a constant contact with the surrounding waters, woods and open-air environments. A large effort is put into the education of medical and care-taking staff. The *Sarah Networks* project idea was founded by orthopedist Aloysio Campus da Paz, in cooperation with the architect Jao

Filgueras Lima. They met when Lima was under the medical custody of da Paz's.

The policy of *Sarah Networks* allows development, research and material production to stand in close relation to the needs and desires of personnel and patients.



This means for instance that the adjustable beds in the patients' rooms, sign-posts, as well as the chairs and benches in the common spaces are fabricated in special workshops managed by the hospital.



Figures 4, 5, 6. *Sarah Networks* rehabilitation hospital, Brazil.

One example of patients' participation is the possibility for one patient to make a decoration to be framed and hung in another patient's room.



Figure 7. Sarah Networks: Patient to patient involvement.

In the cases of *Love and Devotion* and *Sarah Networks*, the principle of participatory engagement is shown to be efficient, provided the supporting structure for this is efficient too. A future investigation into the flexibility of such possibilities and their implementation in the organization of hospitals has the possibility to increase the good effect of environments on the wellbeing of patients and personnel, to costs far less than those for large scale rebuilding or refurbishing of whole units of care.

2. DESIGN PROPOSALS FOR WAITING ROOMS

Waiting rooms are a kind of last instance of "normal life" before the waiting person enters into a world where she is treated as a "clinical object". These facilities for regulating the individual space-time of waiting, and guiding a person that comes and leaves the hospital, are of special interest as concerns both their task of providing temporal relief, as well as their capacity to reflect, or remind of, the world outside the walls of the clinical institution.³ A pilot study made by the research group, about artworks placed in waiting rooms, shows that thematic artworks should be carefully selected. Picture motives that would work well in a gallery situation, can in a waiting room give unexpected rise to associations with illness, medical treatment or pain. A painting with the compassionate aim to interpret a difficult disease situation, risks being contrarily judged, when exposed to a person who is waiting to get a diagnosis.

³ For the notion of "waiting" and its connection to physical urban space, see Kärrholm/Sandin, [7].



Figure 8. Landskrona Hospital, Eye clinic: art work in waiting room.

And supposedly "safe" or "nice" motifs, like animals for instance, can, if rendered too realistically, in certain situations become frightening.

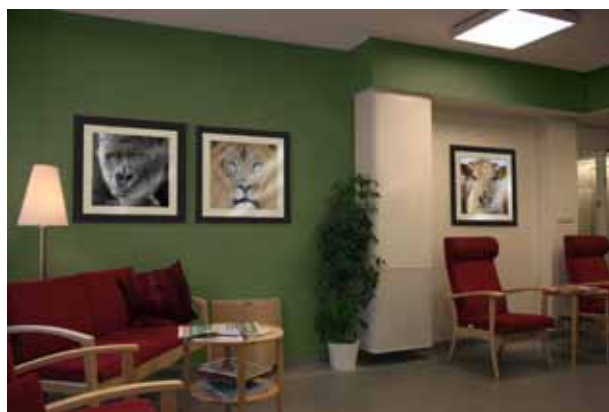


Figure 9. Wall decoration for waiting room, students' project.

As a part of the study of waiting rooms, the research group initiated a students' project, where ten clinics within The Malmö/Lund Hospital SUS co-operatively provided background material as regards documentation of current state, as well as making verbal suggestions about what could be improved.⁴ The students worked on logistic, experiential, as well as mere visual alterations of these ten spaces, and the resulting proposals were shown to professional clinical representatives, and in one case in a specially arranged meeting with the complete staff and

⁴ Course design by Petersson and Ståhl [15]. Evaluation and critique of student's works: Björgvinsson, Petersson, Sandin and SUS hospital representative Sue Harden.

leadership of one clinic department. Several of the projects aimed at a clarification of functions such as queuing, sign orientation, visual overview, etc, while others concentrated on the general aesthetic or artistic impression. A design proposal generally carries several programmatic solutions to the “activity” of waiting, but sometimes this attempt to clarify also becomes a restriction to the spectrum of waiting possibilities [7]. In the students’ design proposal project it was also noted that cultural differences are important with regard to what types of motifs and colors that will have a supposed effect, and which ones that can have effects opposite to the artists/designers intentions. It was also noted that in existing environments, the simple act of labeling rooms and art works were generally made in Swedish language only.

One of the students’ projects [12] was – after an open meeting discussion at the clinical site with working personnel and their immediate leadership – taken into consideration by an architecture studio that had the commission to re-design the clinic. Several of the ideas were thus transformed into the waiting room of the new and re-built clinic: the orientation design (larger digits on the doors to the rooms); the personal distancing (to allow eye contact with certain other patients, at the same time as improving privacy and security at the point of check-in); and the visual communication (tearing down of walls but showing a function division-line in floor-coloring instead).



Figure 10. Proposal in Placebo students’ project [12].



Figure 11. Work-place presentation of student’s project.



Figure 12. Wall decoration in waiting room, students project.

The discussions of the waiting rooms’ interiors made it obvious that the issue of placement and maintenance of art could tell something about the material and visual culture of hospital interiors, where spatial decisions, either clearly stated or silently performed, are part of the daily activities.

3. THE VISUAL TRACES OF MAINTENANCE

A third, ongoing, part of the project concerns the effects of rearrangement actions taken at the hospitals, of commissioned art installations. Such alteration, or extinction, shows the historical succession of hospital’s public art policy, i.e. how the artworks are experienced and commented, or physically damaged and taken away. In the process of an art commission, proposals are often made and evaluated by an expert committee. However, at times the decisions made by this committee can be overruled by local authorities or personnel.

As a part of the *Placebo* project, a series of photos have been made to illustrate changes in conditions and attitudes concerning health care and works of art. Often, the art works, the furniture and the daily routine objects interfere spatially. The photos are used in exhibitions, in order to bring out comments about the aesthetical preferences and decision processes for the selection and maintenance of art.



Figure 13. Store 1, in a series of photo documentation of public art at stores 1-6, entrance 73, SUS, Malmö.



Figure 14. Store 4, in a series of photo documentation of public art at stores 1-6, entrance 73, SUS, Malmö.

4. PATIENTS' OWN DOCUMENTATION

One of the *Placebo* investigations is carried out as a participatory project, where patients will document their immediate hospital environment with handed-out cameras, while at the same occasion also being asked to make their own suggestions about spaces that they experience as good, in the sense providing a state of well being. These patients are thus encouraged to participate in the making of proposals for improved healing medical environments, proposals that will be collaboratively discussed with people in the hospital organisation.

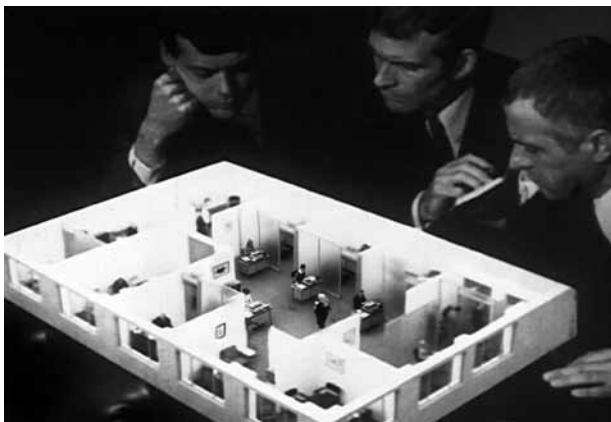


Figure 15. Example of questionnaire image.

As part of the questionnaire about preferred spaces, and the request to take photos, the patients are also exposed to printed images that in various ways may stimulate the action of making their own photo documentation. These images have been chosen to appeal to a broad sense of pictorial experience, and to bring a pictorial content about spatial arrangements, or people acting in spatial situations.

In a first negotiation process this project was approved on a local level within the hospital's organization, however the board of the hospital introduced a stricter regulation of the handling of cameras in the hospital, partly due to the ever-increasing use of mobile phones and social media including

internet distribution of pictures taken privately. It is of importance in this part of the project, as well as on a more general level, that the implementation of media in the health care context can contribute to the daily meaning-production in that context, and not only as a means, or an effect, of a detached research investigation [3].



Figure 16. Example of questionnaire image.

5. PLACEBO EFFECTS IN LIFE PASSAGE SITUATIONS

The passage of life is often at stake in hospitals: life tracks are altered, children are born, and people die from diseases or as an effect of accidents.

Malmö Hospital SUS hosts a funeral chapel adjacent to the Pathology Department. Here you can find localities where not only patients deceased in the hospital, but actually all the dead citizens of Malmö, pass through before being laid in coffins and collected by funeral directors. The funeral chapel also contains rooms used for the final visual display and last goodbye of the deceased.

The modernisation of the procedure of preparing the dead body has left one of the rooms in the chapel in an undecided state, which has led it to become more or less a place for storage.



Figure 17. Funeral chapel, former preparatory room.

Of special interest here is the question of whether the design of the chapel – its interior decorations and its exterior arrangements – signals the presence of death and to what extent it assists people in the process of grief. The decorations in the funeral chapel's waiting room seem to be low-key reminders of death, present in the choice of decorations, as well as in the colors and materials of the furniture. However, at a closer look this decoration strategy reveals a fear of cultural and religious conflict. A general difficulty in situations of death and the treatment of dead bodies is the fact that cultural and ethnic traditions and customs often become strongly articulated. Because of this it is difficult to make general suggestions when it comes to the design of spaces related to death; leading to a risk that they become aesthetically unarticulated, vague or eclectic. However, there are cases to be found where these difficulties have been handled in a more experimental and artistic manner, and a future investigation could be to see if those environments are functioning well from an ethnical, cultural and post-secular perspective.

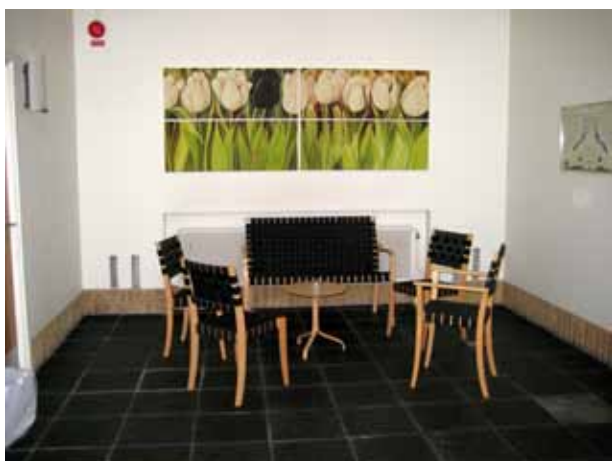


Figure 18. Waiting room in funeral chapel, at SUS, Malmö.

6. THE GRAND HOSPITAL AS HISTORY OF POLITICS

Hospitals are mirrors of the political development of societies. The film *Zagreb University Hospital* is a *Placebo* part project that considers the ontological question about what matters in the complex relation between judgement of health and judgement of national survival.⁵ The film addresses these issues and how they are mirrored in infrastructural changes at a societal level by observing cycles and contradictions in a variety of hospital-related circumstances. The base in this project is the never completed Zagreb University Hospital. The construction of this hospital in the outskirts of Zagreb was started in May 1985 after a referendum involving the citizens of the city. A new hi-tech hospital was needed, with specialists and

expertise that could serve all Yugoslavia, not least in case of war. At a specific location close to the Sava River a gigantic underground hot water spring would serve the building with hot water and heating. The basic structure of this huge 1000 bed hospital was erected, but when the Balkan civil war broke out the construction work was stopped. At this point three large halls were completed with doors, windows and electricity. But the need for financial support for the war machine was considered stronger than the need for a large-scale health facility. The storage capacity of the building was partly used for ammunition and weapons instead. After the war the unfinished building was gradually stripped of functioning parts and valuable metal. The gigantic skeleton of the building resists weather and wind, while the nature is invading the rooms and the roofs.



Figure 19. Abandoned hospital architecture, Zagreb.

Not far from the ruins of the hospital, along the Sava River, a golf course is situated. The Zagreb Golf Club was established on ground that was planned for social housing, and raised a lot of debate. The golf course and the golf club function in the film as detached but related spatial actors.



Figure 20. Abandoned hospital architecture, Zagreb.

The film project thus addresses health care architecture in a historical and political context through a cinematic bricolage of architectural materiality, visual renderings of the surrounding material culture (golf course, etc.) and with

⁵ The film project is made in co-operation with Magnus Bårtås, artist and professor at University College of Arts, Crafts and Design, Stockholm.

a visual supplement of other aspects of health related processes.

One particular media aspect of the making of this film is the use of “found circumstances” as part of the methodology in the film production. So, for instance, the abandoned building works as a stage set-up for its own documentation, and the special vehicles for transport at the nearby golf course were used for the take-up of moving camera sequences.

7. RESEARCH PRESENTED IN THE MEDIA STUDIED: COMICS AND HEALTH

In June 2010 a conference was held at the University of London, on the subject of Comics and Medicine: Medical Narrative in Graphic Novels. Since one part of our study of the visual culture of hospitals had been the commercial magazines, from 1960's and on, where hospital situations were illustrated in drawings or colored graphic designs, we saw a suitable opportunity to align these studies with the artistic methodology inherent in graphics and comics. At the same time we saw a possibility to announce our embryonic research interests in a “comic strip” form. We decided to participate through a printed folder with constructed visual narratives that in a conference situation could be quickly grabbed and grasped.

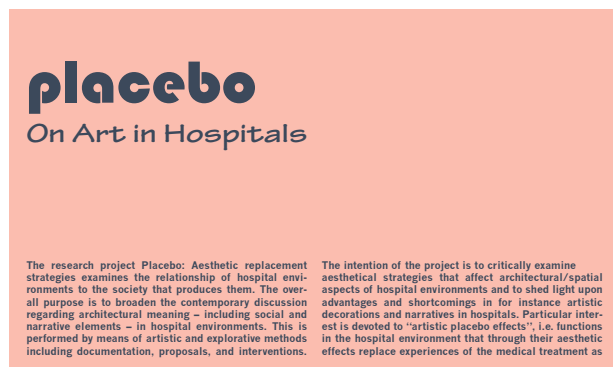


Figure 21. Front page of folder presented at Comics and Medicine conference, University of London, 2010.

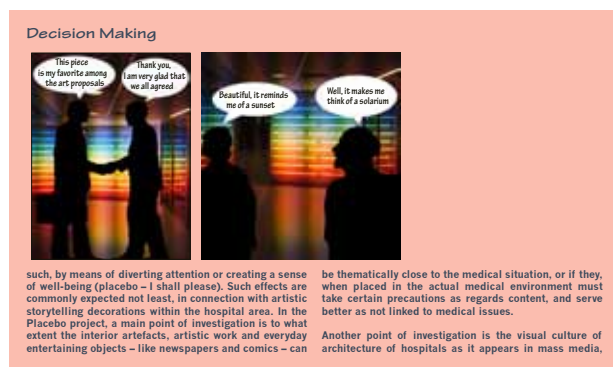


Figure 22. Conference folder, about aesthetic decision making.

The printed matter was titled *Placebo: On Art in Hospitals*, and focused on possible scenarios of decision-making in public art commission situations.

The participation by the research project in the graphic discourse led to a collegial discussion about the presence of graphics in health care, and the possible future investigation of, on the one hand, the culture of printed matter in waiting rooms etc, but also on the methodological input that the comic culture can have on the presentation of research results, as well as on the way that a health research project approaches the matters of study. This concerns, for instance, not only the succession of images aspect that is part of the story-telling in comics culture, but also the fact that presentations and investigations may involve also the more subjective speech type narratology of this cultural field.



Figure 23. Conference folder, on thematisation in visual art.



Figure 24. Conference folder, the aesthetics of joyousness.

It was also concluded that drawings, in the sense of freely expressed subjective renderings of a person's own environment, can be used as a probing method, reminiscent of the photographic intervention method described above. What remains to be sorted out in that respect is for instance “imagined drawing competence”, which we have judged as a possible risk of restriction (“I cannot draw”), but preferably something that can be eliminated, if the design (drawing) tasks can be designed to allow even the simplest visualization of ideas.

CONCLUSIONS, FROM A MEDIA AND METHODOLOGY POINT OF VIEW

As have been shown above, the sub-projects under the *Placebo* umbrella have the common ambition to stimulate various types, and degrees, of participation involving patients, personnel, and authorizers of the material artistic presence. Partly as an effect of this attempt, another common and important feature of the sub-projects has been to activate in the research process a methodology that can be found in the actual case studied. In other words, it has been fruitful to let the studied subject in certain aspects conjoin with the subjectivity of studies. Thus, to the extent that the research here has been able to “follow its actors” [8] in order to let these actors show not only relevant research issues and possible tracks of interest, but also actual methods for investigation, we conclusively suggest that for research in general it could be beneficial to look at media not only as a presentational or result-oriented feature, and not only as a data-collecting tool, but as a methodological “guider” as well. Such is for instance the intention with the handed-out cameras, or the design suggestions for the waiting rooms and the hospital funeral chapel. This means also that the media at hand can be a direct reflection, as well as a factual ingredient in the object of study, such as when the transport vehicle in a film where that vehicle plays a figural part could also be used for the film production as such, or when the participation in a conference about the role of comics in health care was produced as a pamphlet with a comic strip type of announcement of the problems of interest. Thus, the methodology of the *Placebo* project has here been shown to contain situations where the research methods may be seen as partly playing on the same ground as the visual and material culture production linked to hospital architecture, and the maintenance of hospital buildings.

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Working Patches

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ABSTRACT

This paper addresses accountability in academic and artistic writing. The narrative position of the patchwork is used to tell stories of the travelling exhibition *Threads - a Mobile Sewing Circle* since it allows for fragments and multiple voices and perspectives, but still hold together. Throughout the text partial connections, alliances, as well as separations are traced, to tell stories of inclusion, and exclusion, of being knowledgeable and not.

Keywords

Patchwork, accountability, killjoy, DIY, sewing circle, academic writing

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When Design Meets Art and Turkish Culture. Lessons Learned from Making.

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ABSTRACT

Worldwide social, economic and political changes have altered not only our lives but also art and design and its meaning in society. It is time to revise our frame of reference and criteria. The questions in this paper relate to socio-cultural awareness: how and in what way can designers meet with artists as to build a bridge between different cultures? How and in what way does this meeting and active collaboration of different perceptions and approaches on identities and heritage consolidate the rich cultural diversity of Europe?

Linked to the actual setting of the city of Istanbul as cultural capital of Europe in 2010, questions relating to this cultural context have been initiated by a group of art and design students from Brussels (St Lukas), Eindhoven (TU/e) and Istanbul (ITU), resulting in a short-term exhibition in Istanbul as a showcase of their artistic and design outcomes.

The present paper follows the track of 3 Eindhoven design students. Within Ludvigsen's framework of social interaction [9], it presents and analyses motivational drives and strategies of the reflective and transformative design process and prototyping, as has been set out by Hummels and Frens [3]. To conclude it takes a closer look at the differences between the educational cultures of art and design and what lessons can be learned in the future.

Keywords

Design, art, cultural understanding, social space, dynamic interaction

INTRODUCTION

Confronting different visions on Turkish values and identities by way of installations has the support of Lifelong Learning Program Erasmus for IP. Independent experts assessed the project as follows: *'Europe is looking for new talents, but also the topic combining Industrial Product Design and Visual Arts and Media students with students of the Technical University of Istanbul in the way described in the proposal is very new. [...] It is not only*

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Figure 1. Galata Bridge with the theme of the culture capital 2010.

bridging the gap between different cultures and historical backgrounds, but to look in a different way to make a win-win situation in a way students can look and learn from people in societies instead of focusing on culture differences from only a Western point of view, which is good for creativity, peace and mutual understanding. To learn to look from a different angle will result in new designs, visual arts and media. A real contribution to the process of accepting Turkey in the EU: Istanbul can bridge the gap between Western Europe and Asia.' And: 'If the IP is seen as a starting point for a further, bigger project, the organization is worthwhile. It will have an impact on social inclusion of people of different cultures in Europe, e.g. by the use of social networks.'

Building bridges between the cultures

How and in what way does our perception of Turkish cultural values differ? How to build a space pointing at the cultural similarities and differences? The approach to these culture related questions was threefold: it was done in context, focusing on perception – moving and feeling - and it was communicated through interactive installations.

First, part of the project was carried out in specific neighborhoods of Brussels, Eindhoven and Istanbul in order to cope with the diversity and richness of Turkish culture; relate the perceptions, examples, stories, experiences and sensations together; and deal with

stereotypes while analyzing Turkish and defining multiple Turkish identities.

Secondly, the approach was one of perceiving the world, as James Gibson argued in his *Ecological Approach to Visual Perception*, along a 'path of observation' [2, p.197].

Thirdly, along this line the exhibition space was regarded as a medium to concretize the multifaceted Turkish cultural context by way of (interactive) installations; allowing the experiences not only to touch the eyes or the visual sight, but also involving the senses of touch and/or hearing as aspects of a more bodily orientation towards our surrounding.

In the following sections we further develop these 3 steps with quotes from students, coaches and experts as a way to illustrate personal reflections and design rationale.

SETTING THE STAGE

Industrial design students from Eindhoven were involved in this project, along with product design students from Istanbul and art students from Brussels. The artists participating consisted of a mix of photographers, sculptors, video-makers and performers. The project started with a wide array of lectures, workshops and brainstorm sessions, as to confront all participants with and deliver them a theoretical and practical framework on cultural values and identities, linked to their specific neighborhood. In this section we look at lecture topics on ethnography and activities like the Laban Movement Analysis as relevant introductions to the stage setting of the project.

Ethnography and practice of walking

Tim Ingold's publication *Lines* [5] was considered to be a general point of reference to all participants for its social reflection, methodology and idea/vision upon nowadays society. In his ethnography and practice on walking, Ingold imagines a world in which everyone and everything consists of interwoven or interconnected lines. Drawing on a multitude of disciplines including archeology, classical studies, art history, linguistics, psychology, musicology and philosophy among other, he lays the foundations for a new discipline: the anthropological archeology of the line. To put it in terms suggested by historical geographer Kenneth Olwig, the line of wayfaring or travelling, accomplished through the practices of dwelling and the circuitous movements they entail, is *topian*; the straight line of modernity, driven by a grand narrative of progressive advance, is *utopian*; the fragmented line of postmodernity is *dystopian*: '*Perhaps it is time we moved beyond modernism's utopianism and postmodernism's dystopianism to a topanism that recognizes that human beings, as creatures of history, consciously and unconsciously create places*' [5,p.167]. '*Thus the knowledge we have of our surroundings is forged in the very course of our moving through them, in the passage from place to place and the changing horizons along the way*' [5, p.88].

Neighborhoods as hyper-local places

During their exploration research, the Eindhoven and Brussels students attended specific lectures by experts like Tim Cassiers [1], specialized in the Brussels Brabantwijk. He supported the ethnographic explorations by Ingold [5] with contextual and geographical information about historical developments in the specific northern area of Brussels. In his presentation he specified that looking at this specific neighborhood and its urban tissue from a Turkish point of view help overcoming generalizations: '*Neighborhoods are complex issues. They are not just locations or spaces. They are hyper-local places: the Turkish community is very present in this Brabantwijk. Most of the Turkish people live around this area, called 'little Turkey'. They are inward- oriented towards this place, and oriented towards their homeland. Apart from this hyper-locality there is a trans-national issue, linking/connecting this area with specific locations elsewhere in Turkey. Urban tissues are complex. They not only are about territory. They also are about scale and networks, linking this community to Turkey and other ethnic groups in the city and elsewhere in Europe...*'

Culture, behavior and movement

Cultural values and differentiations can be singled out in the way we behave. By way of choreography it can be discovered how people use their body and interact in different ways. The Laban Movement Analysis (LMA) offers a rich set of elements that qualitatively describe movements. The movement language is relevant both from a mover and a spectator point of view. This means it is used to analyze and synthesize movements. A workshop by Roos van Berkel, dancer and performer coaching at the TU/e, introduced Eindhoven and Brussels students into the four basic components of the LMA: Effort, Body, Space and Shape. One example: masculinity as a movement is concentrated around the hips (strong weight in the Laban model). Femininity comes from the shoulder and is perceived light weighted. Lightweight movement is defined as delicate, gentle to make one feel light as a feather. This workshop was of particular importance for the development of the sound installation, as will be discussed later.

Mapping the walking through Turkish culture

At the ITU, Istanbul, the project started with a brainstorm session about social interactions, attitudes, expressions, values, tastes and desires; resulting in a mindmap on Turkish culture (see Figure 2) that was based on 3 categories (street, society, culture) from a previous research by ITU with Nokia, called The Only Planet [8].

The map allowed the Turkish students to analyze this broad topic and to explore possible research items. '*We decided to record information about our day- to- day observations of people in Istanbul*'. The map divided the Turkish culture in 10 main groups: home, mobility, working, entertainment, rituals, community, food, shopping, street, people. Expanding from these groups, the students identified subgroups, explored habits, behavior, language use

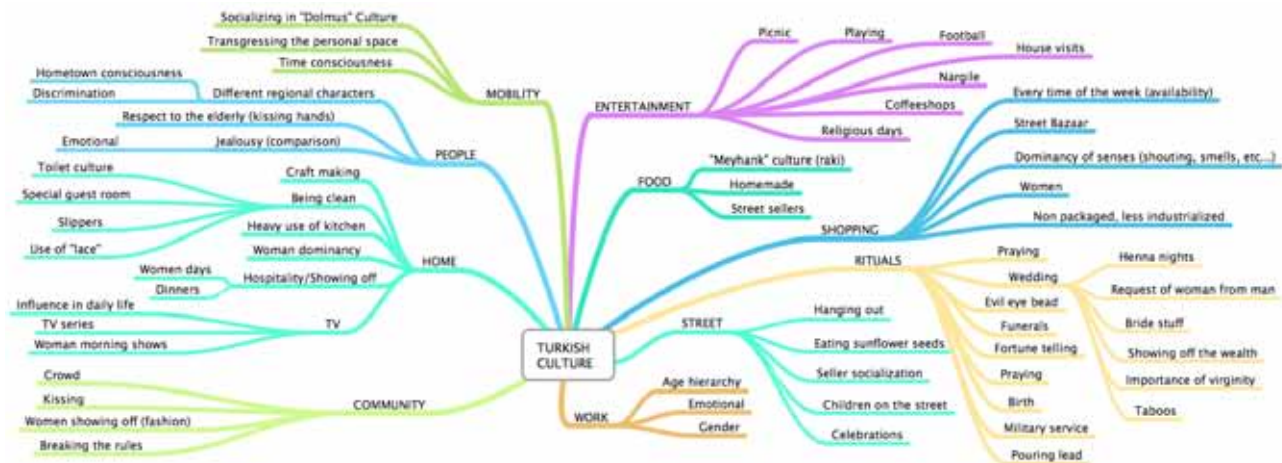


Figure 2. Mind map on Turkish culture.

(including the use of slang and proverbs), and other factors that shape the daily lives of Turkish people. This map was posted on the communication platform (web) and consulted by all participants to position their work.

PROJECT PROCESS

Students were engaged in a reflective transformative design process (RTDP) [3] and supported by co-reflection [11]. The RTDP illustrates different actions or activities, from exploration and experiment in a real context, to ideation and realization. It allows the participants to reflect and comment upon drives and strategies undertaken during these stages. Students also were engaged in a co-reflection process, specially tailored for group dynamics. This specific adaptation of the co-reflection was based on a personal exploration (exploring urban culture), a joint ideation (envisioning interactive installations that allow re-experiencing cultural heritage) and confrontation (developing an exhibition space as a communication and discussion platform). In the following subsections we explore these different stages and look for similarities and dissimilarities between the 3 groups of students that have been involved in this project. Tables illustrate the results of the 3 stages followed by the Eindhoven industrial design students (M,T,N), their drives, motivations and social interactions.

Exploration

During the first half of the project, a lot of time was invested in the exploration, analysis and abstraction of the Turkish culture by way of sensing, perceiving and doing. Insights into the cultural context were gained through personal vision (PV) and societal validation (SV) as motivational drives from the RTDP [3]. Societal validation or context dependent 'knowing-in-action' stimulated design students to focus on people's everyday life, activities, bodily expression, mobility and other patterns in public space as a very specific way of analyzing cultural markers of Turkish communities in their respective countries.

Table 1. Summary of the results from the perspective of the Eindhoven exploration stage.

Name	Label	Exploration	Mot.
M	People	Family connection, warmth, hospitality	SV PV
T	People	Goal oriented vs. Poetic, Message vs. Content	SV PV
N	People	Cultural clash between immigrants and western society	SV PV

Exploration by the Eindhoven students went to family connection (leading to touch); message versus content (leading to sight); cultural clash (leading to sound). These explorations coincide with people as a label within the map. (See Table 1) The Laban workshop, and its practical application upon the Brussels neighborhood, gave N inspiration on how to translate musical notations and create smoother connections between the contrasting values.

The ITU students encountered different neighborhoods. They explored a wide array of particular places in Istanbul such as markets and bazaars, streets, street vending, mosques, teahouses, shopping places, house interiors, transport systems, etc. as to give a lively account of the diversity of their culture. These observations were documented with photographs, drawings and videos, following the guidelines of the mind map.

A personal vision about transformation from our current reality to a new one (through a system or product) also motivated the art students, but in a different person- and context-dependent way. Artists were solely preoccupied with their personal, artistic exploration and looked for a way to confront and let interact their personal vision with a focused perception of the Brussels neighborhood. Their research was more attuned to their previous visual work.

Ideation

During this stage, attention went to design action as a means to get a deeper rooting into the analysis and abstraction of multiple Turkish identities. The analyzing and making drives from the RTDP [3] were used to classify the process: analyzing relates to a more formal kind of information, including literature besides contextual inquiry. [6] Making relates to experiential information that is spawned by design action and takes the form of visualizations as reference points for the other activities. [4] Specific values of the Turkish culture were found and translated into a concept for an interactive installation. This stage was done in Eindhoven together with the local Turkish community (as a one to one relation) in order to create an emphatic communication and understanding of Turkish cultural heritage. During this stage, the students worked out their concept and working model. Table 2 describes the 3 design concepts by way of keywords and its outcome.

The Eindhoven students focused and reflected on multiple iterations, needed for the translation into an interactive physical and electronic installation. They also developed a sense of the ethical aspects of what it means to operate from people's lives. The research rationale by T underlines this approach: *'Through observations of daily activities of Turkish people in Eindhoven I want to see how the shape-based culture is still visible in body language, mobility patterns and mostly social interactions. These visual observations of motions and context will form the basis for developing specific development and visual languages. Expressing this observation in an interactive installation will allow users to experience the Dutch-Turkish culture and get beyond their initial perception of Turkish culture in the Netherlands. Since both spatial movement and social interactions are large parts of this focus area I also intent to use these aspects in the installation [for a sensor sensitive mirror]'.*

In this stage product design students from ITU mainly were making. The physical activities of walking, drinking, going to the market brought them to translate these activities into a physical or tangible prototype. These students mainly focused on physical interaction and developed a list of

Table 2: Summary of the results from the ideation phase by Eindhoven design students. AN stands for analysis; MA for making.

Name	Label	Description	Outcome	Drive
M	People	Trigger to touch Social security	Light Installation	AN MA
T	People	Content vs. form driven communication	Mirror/ Reflection	AN MA
N	People	Individual vs. Collective Femininity vs. Masculinity	Sound	AN MA

possibilities /multiple concepts translating the bodily experience into a design product. As an ITU (exchange) student mentioned on the blog: *'After my initial research [on fortune rabbits or little rabbits on a box] my project is going towards a piece about the fortunetelling rabbits. The concept this far is basically a transparent box. The box is attached to a glove made of rabbit skin. So you put your hand in the rabbit glove inside the box...This creates the idea that you can wear your own fortune rabbit whenever you want to and therefore tell your own fortune.'*

Art students especially were concerned with the analysis of their personal vision. Their approach was conceptual and abstract, and defined by their chosen medium (video, performance, photography). As one art student wrote on the communication platform: *'Right now I'm working on a universal family portrait to put together, based on family traditions... The interaction will exist when the spectators will react on the relations I will suggest.'*

Confrontation at the exhibition space

The different views on Turkish society as outcomes of the individual explorative and ideation phases by the Brussels, Eindhoven and ITU students (outsiders and insiders of the cultural field) formed the start of the confrontation phase. Sharing the preliminary research findings and looking for affinities resulted in a spontaneous, self-organized teaming up in different groups that made up for new, mixed and dynamic configurations. From this stage on, designers and artists developed an exhibition space enabling them to discuss and confront their points of view on Turkish identities. This exhibition was the result of an intensive workshop, held at the Taskısla campus of ITU in December 2010. (See Figure 3) The exhibition configuration and dynamic interaction corresponds to Ludvigsen's framework of social interaction in public spaces [9]: distributed attention, shared focus, dialogue and collective action. This framework is an indication of the group outcome, based on how designers and artists work together and how their work evolved and integrated into an exhibition stage. Four forms of social interaction in public space emerged:

- Distributed attention (DA) is the case when there is more than just one person present in the same public space, but performing their own activity each. As such we encountered the individual work of preliminary staged and filmed performances by art students. They showed their videos at the final exhibition, without changes in concept or set-up.
- Shared focus (SF) happens when multiple persons have their attention on the same subject. These are the works in a group that are presented together but are just related because of the theme. M initially was part of a group of 6 persons, but ended up performing his light installation as an individual set-up, besides the other works of his group. (See Figure 3)



Figure 3. View on one part of the exhibition (photo by O. Tomico) with the mirror installation on the left and the light installation on the right.

- Dialogue (DI) starts to become highly interactive when there is a clear bidirectional way of communication. This form of social interaction happened between T and an art and product design student because of an affinity between their personal vision and societal motivation: in all 3 cases the work handles the part of reflection on culture. This affinity gave T the opportunity to look after other installations (such as a table with Turkish rug) to interplay with the mirror and to discuss the actual content of their work.
- In collective action (CA) there is a clear goal and different people try to achieve it by collaboration. In this project five groups worked together as to make a strong co-operation. One of these groups was formed by N and an ITU student and revolved around the Rabbit of fortune.

Table 3. Summary of the results from the confrontation by Eindhoven design students.

Name	Label	Description	Social inter.
N + design student	Ritual	Rabbit of fortune	CA
M	People	Light installation	From SF to DA
T + art + design student	People	Mirror installation	DI

SIGHT, TOUCH, SOUND

How does design meet art and Turkish culture? In this section we closely look at the installations by the 3 industrial design students from Eindhoven. This specific choice is suggested by how their confrontation with product design and art students revolved around the above-mentioned social encounters. Confrontation started with shared focus and resulted in distributed attention (M), dialogue (T) and collective action (N). (See Table 3) This social shift is strongly influenced by the prototypes and objectives of interaction T, M and N came up with in Istanbul. The prototypes involved 3 modes of interaction with the audience: the sight by way of a moving or rotating mirror which constantly avoids direct reflections of the visitor; a sound interface in which visitors have to navigate and experience a cultural clash, resulting in the 'Rabbit of fortune' installation; and the touch by way of glowing light and slight movement, triggering the curiosity of the visitor and urging him to touch the exhibited object. Let us take a close look at concept, design decisions and exhibition set-up.

Mirror installation

We start with excerpts from the process description by T. About the mirror concept he wrote the following: *'During conversations with Turkish students and literature research an aspect that kept intriguing me was the different approach to communication. Very early in the project it became clear that Turkish communication does not try to capture the content of a conversation as accurate as*

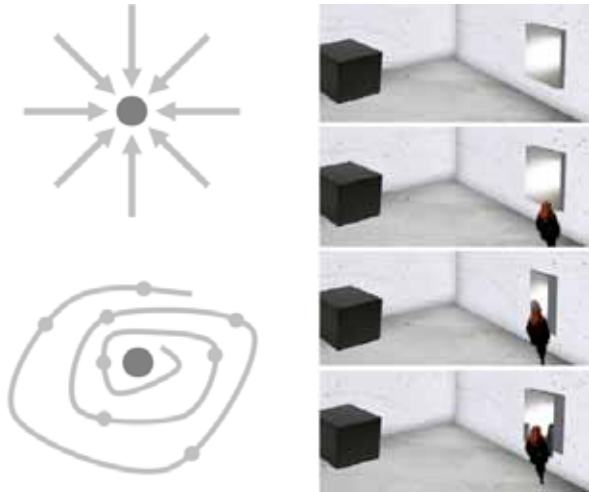


Figure 4 left: Schematic illustrations of the different ways of communicating with content driven communication on top (Netherlands) and form driven communication below (Turkey). Right: Concept scenario of a rotating mirror. The black box illustrates another installation in the exhibition.

possible. Instead conversations often touch multiple surrounding subjects without actually mentioning the precise content. In this way conversations become more colorful and cryptic. (See Figure 4 left).

A difference in communication was the starting point for the following design decisions: *'Through some detours the ideas of using reflections of a mirror came up. Based on the idea of a rotating mirror a concept of a mirror constantly avoiding direct reflections of the visitor was created. When the mirror is approached it will rotate to the left or right. When the visitor tries to follow the mirror it will again move to another position. If the user accepts the behavior of the mirror another installation in the room will be shown in the reflection. (See Figure 4 right) [...] It was decided, after extra research, to continue with a normal, plain mirror and use it as a tool, not as an object. As such it was kept minimal and basic. (See Figure 5) [...] Feedback sessions with a Turkish PhD student formed a strong motivation to continue with this concept. Assumptions on*



Figure 6: Mirror installation during the exhibition, revolving around sight, perception and reflection (photo by O.Tomico)

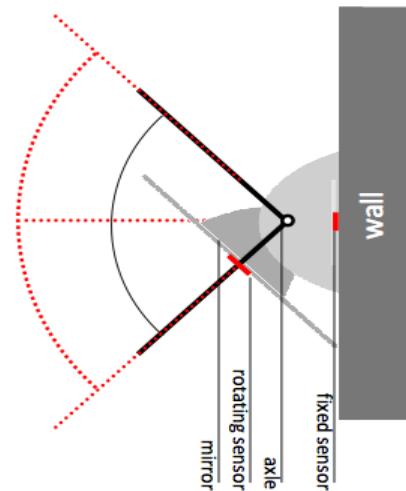


Figure 5: Schematic top view of the prototype. The behavior of the mirror is programmed in Arduino. Red lines indicate sensor range. Black bold lines indicate mirror range.

whether a mirror is an appropriate tool for reflection and if the avoiding behavior would not merely communicate a negative image were tested at the exhibition in Istanbul.'

The mirror led to the following confrontation, as part of the exhibition set-up: *'I formed a group with a Turkish student and a Chinese student from Brussels since our works all directly handles the part of reflection on a culture. For me, this was an interesting part since this gave me the opportunity to actually find an installation to reflect with the mirror as well as discussing the actual content of our works. (See Figure 6) For me that's when the dynamic of the different departments started to evolve. Most important for me about placing my individual process within a group is the different points of view it creates on a subject. I think it is very important to keep in mind that my own vision and interpretation is never the truth for anyone but me.'*

The interactive mirror played a pivotal role in a triangular set-up with the table installation of an art student and a designed product. The original intention was to mirror the art display of prejudices towards another culture by means of a square table covered with Turkish tablecloth and a handmade plate ('What do you think of Turkey?') and wooden blocs or 'did you like' cubes', designed and decorated by a Turkish student with stereotype views of Turkey. This initial set-up was disturbed because of the final choice for an aesthetic exhibition set-up, looking at the moving mirror as an (artistic) object instead of looking at it as a tool to perform a triangular communication and the effect it thus creates upon the viewer. (See Figure 4 right)

Light installation

The concept description by M runs as follows: *'By means of an interactive installation I want to show the audience that Turkish people are a warm people, but might look*



Figure 7: Model of the Turkish cultural values, embedded in the light installation.

distant or cold from the outside. I think this closely relates to the fact that Turkish people tend to create strong social bonds, strong social communities.' (See Figure 7)

About the design decisions he wrote: *'The installation exists of 3 elements, 3 arms. Each arm can sense the visitor and can react individually to the visitor. The arms are placed in a half circle with each arm being able to come close to the other arms. This way the visitor might feel intimidated by the movement of the arms. When the arms aren't touched, they are in their idle state. In this state their heads glow randomly a warm colour, representing the warmth of the people. In addition to this glowing light the arms might move slightly to trigger the visitors curiosity and show that the installation is not static. [...] At an exhibition, it is often not done to touch the exhibited objects. However, by means of glowing light and slight movement I want to trigger the curiosity of the visitor and also his behavior. The installation will then start to 'protect' itself from this disrespectful behavior, because as soon as you touch one element of the installation, it will back off and the other elements will come close to see what's happening.'* (See Figure 8)

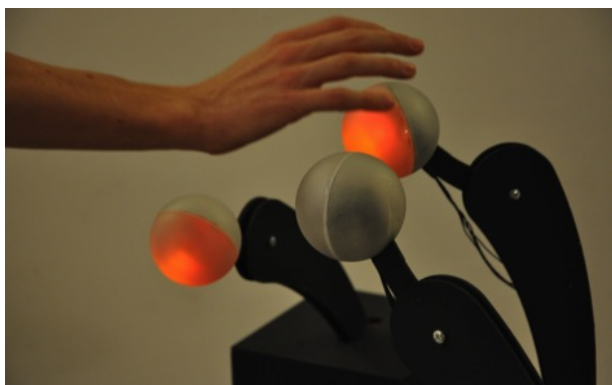


Figure 8: Light installation revolving around touch. Photo of the interaction. One of the arms is touched and moves back. The other arms are moving forward. (photo by O.Tomico)

During the confrontation and exhibition set-up, M came to the following conclusions: *'In order to adapt to the other it is important to first know yourself and compare this with the other culture and then accept and respect the other culture [...] it is about trust in the other's ability, about my own responsibility and that of the others. [...] I have learned that it is important to communicate well and clearly when people with different backgrounds work together.'*

Sound installation

The Laban effort graph (see Figure 9) strongly directed N towards his concept: *'My entry for the exposition consists of an abstract through extraction of the cultural shift that an immigrant goes when he is confronted with our society. This cultural shift is represented by an interface that makes it possible to navigate through contrasting cultural values, represented by abstract translations of sound. [...] During a workshop of Roos van Berkel in Brussels I got inspired by looking at how people move. So in my perspective, if cultural values are present in sound and movement it should be possible to synthesize them myself. I took the liberty to translate 2 cultural dimensions (intuitively based on the Laban model) that were relatively the most contrasting between Turkish and Western society: individualism vs. collectivism and masculinity vs. femininity. [...] In music we can describe individualism as staccato, which is a term for playing unconnected, individual notes. Collectivism is the exact opposite of individualism. [...] So for the synthesizing of the collective part I gave legato the overtone in the piece, recreating the bonding properties. [...] According to Roos, masculinity as a movement is concentrated around the hips (strong weight in the Laban model). When looking at music, we can see that the bass is generally a sound that makes one want to move from the hips as it sounds heavy. [...] Femininity comes from the shoulder according to Laban's theory and is perceived light weighed. [...] To accomplish this sound I used a bell like sample accompanied by light droning features.'*

The explorative research of music and movement led to the following design decisions: *'Creating the interface to*

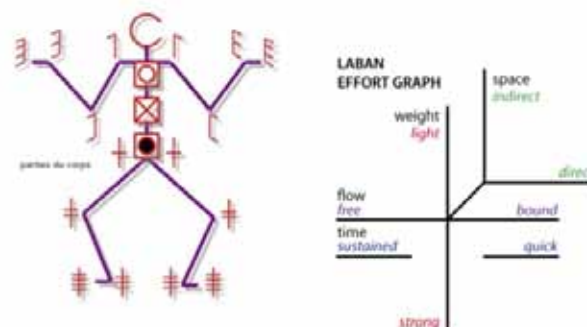


Figure 9: Laban movement analysis and effort graph. Source: http://en.wikipedia.org/wiki/Laban_Movement_Analysis

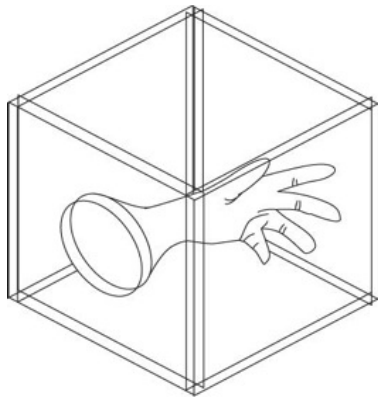


Figure 10: The glove in a box creates the idea that you can wear your own fortune rabbit whenever you want and therefore tell your own fortune. Concept initiated by a Swedish exchange student at ITU.

communicate with Audiomulch caused me quite some hassle since we did not know what kind of space we would have in the exposition. At first I wanted to create an interface that would interact with the exhibitors themselves. [...] Considering the deadline, I was forced to look for another possibility that would work within a few days. By using a wiimote, some open source software and an IR-Led, I was able to mimic an optical mouse. [...] The only facet that was not yet considered before leaving to Istanbul was how the physical interface would look like.'

Searching for an adequate interface was the start of an intensive collaboration with another partner during the confrontation and exhibition set-up: *'After our arrival in Istanbul, each participant had to present his concept. I worked together on the installation with a Swedish exchange student. Her concept did not have a physical form or intention yet but she wanted to express the concept of rabbits and fortunetelling that she observed in Istanbul. According to her, Turkish fortunetellers would approach people and ask them whether they were interested in the telling of their fortune. If so, people choose a rabbit that is presented to them and that rabbit will then pick a piece of paper on which a fortune is spelled. (See Figure 10) I found this concept very intriguing because, in a sense, my concept was doing the same, displaying the fortune of a Turkish immigrant's cultural identity. Instead of having a static ball determining the music, a rabbit seemed to show much more dynamics and story in the installation. [...] Culture is something that you can't control from the outside. This made the fortune telling rabbit, determining its own fortune in cultural identity unconsciously, a perfect interface. To enable the rabbit to act as an interface we then designed a custom made collar with 3 IR Leds attached to it. These Leds were positioned in such a way that it would guarantee visual contact with the tracker of the wiimote. [...] For the final presentation we wanted to raise curiosity within the visitor by placing a tripod and monitor near the table of the rabbit, creating a mysterious monitoring device.'*



Figure 11: 'Rabbit of fortune' installation revolving around sound. (photo y O.Tomico)

CONCLUSION

Research, exploration and collaboration of sight, touch and sound installations illustrate that cultural values need to be experienced and explored before one can realize what cultural identity actually stands for. This paper is not without critical remarks and discussion points. The challenges affecting society today require fresh approaches. How can we continue to make design matter, in dialogue and collective interaction with art and culture?

About topic and previous research

Designers and artists explored local identity and transnational social space. More precisely, they researched the question how and in what way can/must/should their and our perception of and reflection on the Turkish values be adjusted and rectified, as to behave in mutual understanding and comprehension. This moment of confrontation is an important moment of catharsis. It confronts the participants with the way our socio-cultural cooperation is colored by our own beliefs and disbeliefs. It makes them aware of how relevant and irrelevant our face values are. Background and way of working definitely influenced the outcome and decision upon topics as well as on social interaction. Industrial designers engaged in reflective transformative design processes. Product design students looked at symbols and street situations and started to mold this anthropological research into products. Artists started from a personal vision or artistic idiosyncrasy, looking at Istanbul as a new explorative field for their personal research. Distant observation of the neighborhood led to the making of video documentaries that were shown in Istanbul. Because of the choice of video or photography as a medium, a *representation* of the other was present at the exhibition space, turning it partly into a 'cultural' artifact.

About the way of working

As to paraphrase a quintessential research line by anthropologist Tim Ingold [5], who combines approaches from art with anthropology: learning is to understand in practice; exploring the interrelations between perception, creativity and skill. In this specific exhibition set-up,

designers and artists enjoyed teaming up, collaborating and working together as a medium to communicate and share preliminary research findings, looking for common affinities, produce an installation and build up a common exhibition space. One of the primary method lines set out by Ingold [5] turned out to be very successful: self-organization as a dynamic relation or reciprocal interaction of the participants without supervising unit. The most interesting part of the building up of the exhibition was when groups were formed and started to fit and adjust their individual projects together in a natural and organic way, with no interference from outside.

About the exhibition set-up

Discussions emerging from the construction of the exhibition space confronted designers and artists with the way their cultural participation and cooperation was colored by their own beliefs and disbeliefs. It made them aware of how relevant and irrelevant the values rendered are. The exhibition allowed Turkish and European citizens to reflect on the way their perception of and reflection on the Turkish values can/must/should be adjusted and rectified, as to behave in mutual understanding and comprehension. It also gave a chance to discuss the perspectives of how Turkish people counter-perceive their cultural identity from the eye of the Dutch and Belgian Turkish communities. This operation was also indicative to the Turkish community, as they perceive the way we perceive them.

About future work

As a general conclusion we may say that as long as we rely on representational questions or identity construction and the production of representation we remain based on modernistic and Eurocentric methods of identity. We drastically and dramatically have to change this mentality into a new way of thinking and acting. We are in great need of new ideas, of embodying ideas in the concrete. [7] As Kees Overbeeke [10] puts it in *'The aesthetics of the impossible': 'Designers create 'meaning' for people. The implementation of new meaning is what design is all about. In the past this meaning had a functionalistic pitch. We are now heading to a new meaning through a vision on the world and a transformation from our current reality to a new one.'* Or as Caroline Hummels and Joep Frens put it in *'Designing for the unknown' [4]: ' [...] we want to educate students who are able to apply new technologies in ways that are new and daring, driven by a design vision of how*

our world could be [...] people who are able to transform our world [...]'. Only then we might fully succeed to revise and adjust our frame of reference and criteria.

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Applied Research Project Optimum

Generation and Design of Micro Structured Textiles with Spectral Colour Effects

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ABSTRACT

The Topic is the development of a new textile material with nano-structured fibres, which naturally creates new colour effect. Nano-structuring of surfaces causes the reflection of light in spectral colours. By the structured pattern, these effects can be manipulated. This is part of an innovative design approach to fabrics. The colour appearance is no longer caused by chemical dyes but by luminous colours reflected by the textile surface. Based on hologram technology the target is to develop the production process and design for Interior Textiles showing immaterial colour effects in different light settings.

This applied, market-oriented and design-driven research project between Swiss Institutions and Industrial Partners is funded by the Swiss Government [4].

Keywords

Spectral Colour, Textile Hologram, Design Vision, Design & Technology, Innovation, Interdisciplinary Team

INTRODUCTION

This project in the field of Design & Technology we hereby present, results in a product, which is aesthetically and technically innovative and ready to be launched in the market. The team represents the Design Research, Scientific Research and Textile Industry along the supply chain from textile fibre to market and design in Switzerland.

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Vision



Picture visualising the Vision for the project, HSLU 2009

This project has been initiated through a strong design vision: "Imagine there would be Interior Textiles sparkling as diamonds - soft fabrics being apparently colourful in different light sceneries occurring during the day from morning light to darkness." To find understanding and in order to define a common goal within the interdisciplinary project group we have created an image representing the vision. Later on we as well used language to describe the goal with terms and definitions we all agree from different points of view.

The Goal of the Project

The topic is the development of a new textile material with nano-structured fibres, which creates naturally new colour effect. Based on hologram Technology the target is to develop the production process and design for Interior Textiles showing immaterial colour effects in different light settings.

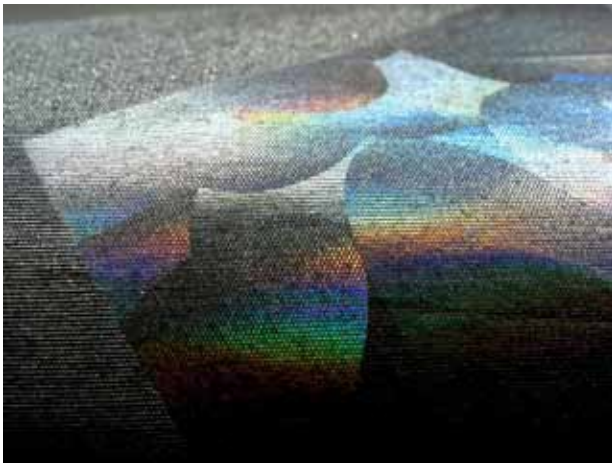
Research Questions

-How can the use of nano-structure create a new impression of colour as part of textiles?

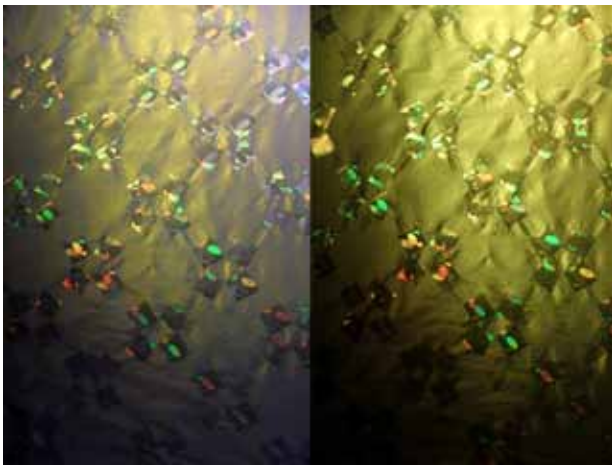
-Which fibre other than synthetic Monofilament is applicable for nano-structuring, has textile surface feel and can be processed by a weaving machine to industrially weave fabrics?

-How can a textile production process from fibre to finished fabric include the step of nano-structuring the surface to achieve the new iridescent colour effect?

DESCRIPTION OF THE RESULT



Detail of the Hologram Textile with Spun Yarn, HSLU 2011



Hologram Textile with Spun Yarn in 2 different light settings, HSLU 2011

Shimmer and Shine at its best:

The hologram fabrics may be described as a textile material, which constantly and infinitely reveals colourful appearance of an ephemeral character as a new textile dimension. The combination of the hologram technology with the softness of fabric increases the attractive potential of the material as

within angles and moments it constantly changes its appearance by reflecting the light of the surrounding. Supposed there is light enabling the perception of colour, one could say that moment-by-moment the viewer and its viewpoint make the look of the fabric. An interior ambiance featuring hologram textiles is visually enriched including a specific light source revealing the iridescent colour effect. In this case the textile surface is materialising the lightness of spectral colours and in exchange the light is embellishing the fabric, which results in an atmospheric lightness.

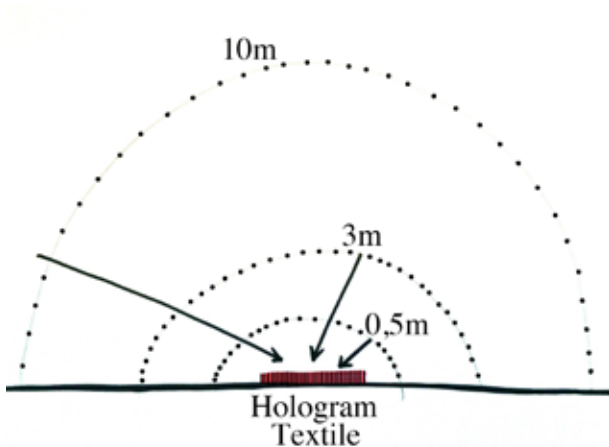
PROJECT PLAN AND OUTCOMES

From a design perspective the hologram look on textiles so far is known as a foil transfer and not yet realised as part of the textile fibre structure resulting in a Textile with soft feel. Now existing thread materials with iridescent look are plastic foils (not fibre threads) with hologram, which are cut into small plastic ribbons, known as "Lurex" thread [5]. Regarding textile fibres and nano-structuring the achievement of the Swiss Federal Laboratories for Materials Science and Technology (EMPA) is a hot embossing process on single monofilament fibres [2][3]. Thereby a small nano-structure can be transferred on the surface of the fibre, which reflects light in luminous colours. The technology of Hologram and nano-structuring is widespread in packaging industry for safety reason, branding and design in order to identify originality of products [1]. Hologram has not yet been realized as part of the textile manufacturing process.

Design



Woven Sample to test Visibility of Colour Effect in early Stage of Project, HSLU 2009



Plan to test Visibility of the Colour Effect from different distances and angles, HSLU 2009

The target is to achieve clear visibility of the colour effect on interior fabrics. The colour effect should be seen from close distance as well as from far away (0.5 meter to 10 meters). The weaving construction of the fabric and the design of the hologram and its placement on the fabric (Textile Design) have to be defined accordingly to reveal best possible colour effect.

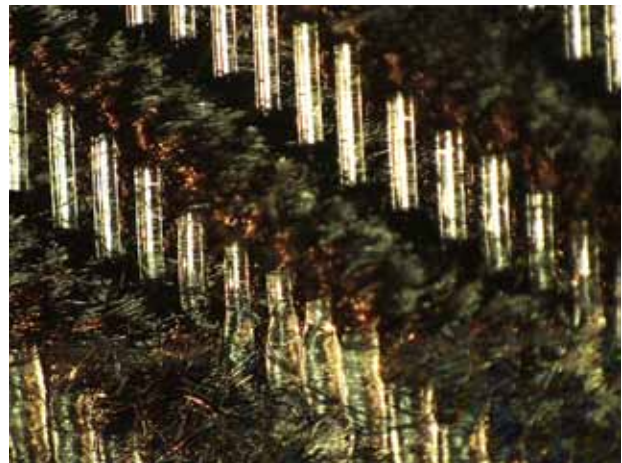
Deliverable: A fabric collection for interior textiles showing an innovative colour effect interacting with different light sources (artificial and natural).

To carry out research on the visibility of the iridescent effect in distances from 0,5m to 10m we fixated different samples of hologram fabric on the wall and observed the effect in angles within 180°. This test should represent real situations in interiors in which the textile may be used. The hologram effect was developed and tested on different synthetic fibres made by different weaving constructions into a hologram textile.

Textile Fibre



Monofilament fibre with embossing, EMPA 2008



Detail of woven Structure with Monofilament partially embossed, HSLU 2010

The hot embossing on the monofilament fibre PMMA on a nano scale has successfully been done by EMPA in an experiment on thermoplastic amorphous or semi-crystalline polymers [2][3]. It creates a luminous colour effect by reflection of light on its surface. The problem is that synthetic fibres suitable for nano-structuring (embossing) are difficult to process, because it is not elastic but brittle, fragile and tends to break if tension or bending happens. Woven into fabric this monofilament creates a star surface. Therefore the target is to find an embossable fibre, which is softer as fibre than monofilaments and which can be made into textile surface.

Deliverable: Applicability of fibre for nano-structuring which is fulfilling bend ability, softness, textile fastness and processing.

To achieve the textile feel of hologram fabrics we had to identify fibres which can be treated with the nano-structuring process. Therefore it is required that while transferring the hologram on to the fibre the hot embossing can change and rearrange the molecular structure of the fibres not only short-term but long-term. We successfully discovered and applied a synthetic spun yarn with good ability for weaving on the industrial loom in different constructions without yarn breakage. This yarn as well fulfils the technical requirements; it has a competitive product cost and results in a satisfyingly soft woven material.

Production Process

The process of embossing of textiles does not exist as industrial process on a nano scale and newly has to be integrated into the existing textile production chain. It has to be evaluated if a) the fibre will be embossed or b) the finished fabric will be embossed. Both models result in a different production process. Fabrics are manufactured as running meters, it should finally be scaled up to a continuous procedure in order to result in an economical cost of product.

Deliverable: Prototype of a continuous production process for textile surfaces including nano-structuring process (embossing).

To achieve a marketable product range of the hologram textiles it is inevitable to consider embossing the finished fabric instead of embossing the single yarn. Therefore the production process is defined as a refining “finishing” of already woven material. This allows companies to produce the hologram textile on demand, working from specially prepared fabrics in stock, which are kept ready for “finishing”. From a design perspective we have evaluated several concepts of how to perform the embossing procedure continuously. The target is to minimise the technical restrictions in order to have maximum liberty in designing the pattern of the hologram, choosing its dimension of the repeat and develop its proportion, product language [6] and expression according to the target groups and settings it will be used in.

CONCLUSION FROM A DESIGN PERSPECTIVE

However the result so far is a fabric with a new visual dimension. The textile material is showing iridescent colour change caused and challenged by an external stimulus such as movement or changing light. The spacious experience with hologram textiles may be described as an ongoing dialogue, ready to be activated anytime by the viewer looking at it and being supported by the influence of light. We consider fabric no longer being of static character but expressing an almost immaterial lightness through divers and dynamic interaction with the surrounding, light and its viewers.

Explication of Technical Terms

Nano-Structur: relief including different angles in very small dimension (Nano). This relief causes fragmentation of light and its reflection as rays in any colour.

Monofilament: endless thread made of synthetic origin in a spinning process, comparable to a wire of small diameter.

Spectral colour: single ray of light, which our eye perceives as colour impression.

FIGURES

Volume of Project is 440'000.-Swiss Francs

Project Start 1.June 2009, End May 2011

Project Lead: HSLU/ University of Applied Science & Art Lucerne Prof. Dr. Andrea Weber Marin, Isabel Rosa Mueggler, Prof. Tina Moor

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A New Type of Colour Change in Smart Textiles

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ABSTRACT

In this paper, a new method enabling colour change in textile structures has been developed. Currently, in colour change, various solutions may be found in the literature. They depend mostly on stimuli that trigger the change. Thermochromism, whereby a change in colour occurs with a change in temperature, is already well-known in textile [5]. In this article a novel technique based on electrochromism applied to flexible textile structures has been carried out. Numerous experiences have been undertaken on flexible substrates such as PET films. The aim of our study was to adapt that technology to textile structures. Therefore a sandwich structure containing a thin spacer textile with electrochromic compound (Prussian blue) and two electrodes; bottom and upper (transparent) has been developed and produced. This structure is able to generate, if powered with low voltage, reversible colour changes. The switching time is approximately 5 seconds at 4.5 V voltage.

Keywords

Smart textile, electrochromism, electrochromic textile

INTRODUCTION

Any changes in the colour of an object, whether this is from white to black, colourless to coloured or from one colour to another, can be easily detected by the human eye or by using simple spectrophotometric instruments. Such changes in colour provide important visual signals that can be used to convey information to an observer, the most obvious being traffic control signals. Consequently, research into chemicals that undergo reversible colour changes upon the application of an external stimulus has been extensive. These colour change phenomena, chromism, are classified and named following the stimulus that causes the change. [1]

In most cases, the chromism is based on the change of the electronic state of molecules, specifically the state of the electron σ and π , and this phenomenon is induced by

external stimuli which can alter the electron density of the substances involved. Many natural compounds have this feature, and many artificial compounds with a specific chromism have been synthesized so far.

In this article an electrical stimulus was chosen. This type of colour change is also called an electrochromism

Electrochromism is a reversible colour change of a compound when a redox current is applied. This reversible colour change is due to oxidation–reduction reaction. The colour change between two colored states, one of this state may be transparent.

This optical change is effected by a small electric current at low dc voltages ranging from a fraction of volt to a few volts (0 to 5 V). This small electric current is a current of reduction-oxidation reaction. [15]

ELECTROCHROMIC MATERIALS

Numerous chemical materials, organic and inorganic, exhibit colour change in a persistent but reversible state by an electrochemical reaction [Table 1]

Table 1: Most used electrochromic compounds. [3]

Inorganics		Organics		
Transition metal oxide	Iron Hexacyanoferrates	Conductive polymers	Viologens	Metallopolymers

Inorganic electrochromic compounds

Electrochromic inorganic products have been well-known in beginning of electrochromism. The most used compound have been listed in table 2. [3]

The Transition Metal Oxide (TMO) films have been deposited by several techniques such as vacuum evaporation, sputtering, spray deposition, electrodeposition, electrochemical oxidation of tungsten metal, chemical vapor deposition (CVD), sol–gel methods, etc. The TMO films can be electrochemically switched to a non-stoichiometric redox state which has an intense electrochromic absorption band due to optical intervalence charge transfer. [15] A typical and most widely studied example is the tungsten trioxide (WO₃) system, since its electrochromism was first reported in 1969. [2,6,7]

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Prussian blue [PB, iron(III) hexacyanoferrate(II)] is the prototype of a number of polynuclear transition metal hexacyanomellates which forms an important class of insoluble mixed valence compounds. Although, PB has been an important inorganic pigment and has been manufactured on a large scale for use in paints, lacquers, printing inks and other color uses, not much was known about the electrochemistry of PB. [15]

Table 2: Examples of inorganic electrochromic products. [3]

Transition metal oxide	Iron Hexacyanoferrates
e.g. WO ₃	Prussian blue [Fe ^{III} Fe ^{II} (CN) ₆]
e.g. V ₂ O ₅	Prussian green [Fe ^{III} ₃ {Fe ^{II} (CN) ₆ } ₂ {Fe ^{II} (CN) ₆ }]
e.g. TiO ₂	Prussian white [Fe ^{II} Fe ^{II} (CN) ₆] ₂
e.g. Nb ₂ O ₅	Prussian brown [Fe ^{III} Fe ^{III} (CN) ₆]

Organic electrochromic compounds

Currently, this electrochromic effect is being studied not only with inorganic materials but also, and largely, in organic compounds such as conjugated polymers, viologens, metallo-polymers and metallo-phthalocyanines, as reported in Table 3.

Organic electrochromic materials offer several advantages with respect to inorganics, not only in terms of flexibility, ease of processing and low cost, but also with respect to both 'tailorability' and efficiency of coloration. [4]

PEDOT is a widely used conducting polymer suitable for several types of applications. [7]. This polymer and its alkyl derivatives show typically cathodically colouring electrochromic properties. Therefore, they can be used also in combination with anodically colouring materials (most of conducting polymers), in order to develop dual polymer devices. [4,14] Polypyrrole (Ppy) and polyaniline (PAni) are two more examples of conducting polymers subject to wide investigations (not only for electrochromic applications). Ppy shows a blue/violet colour in oxidised state, while the neutral state (undoped) is yellow/green. [11-13] PAni is polyelectrochromic, since in various red-ox states it can show several colours, such as yellow (leucoemeraldine), green (emeraldine salt), blue (emeraldine base) and black (pernigraniline). [12,13]

The use of conjugated polymers in electrochromic devices permits a fine tuning of colours. This represents one of the greatest advantages of choosing organic compounds rather than inorganic materials. Colour control in electrochromic polymers can be easily achieved by following several strategies, such as group substitution (monomer functionalisation) aimed to modify the polymer

conjugation lengths, copolymerization of distinct monomers.

The strategies adopted for conjugated polymers in order to obtain colour control are also used in other organic compounds, such as viologens. For instance, intense colours shown by reduced viologens can be modulated by opportune selection of suitable substituent groups. In particular, blue/violet or green colours can be shown by using, respectively, alkyl or aryl groups. [12,13]

In addition to viologens, metallo-phthalocyanines form another class of organic non-polymeric materials studied for electrochromic devices. Their molecules have a metal ion (M) which can be located either at the centre of a phthalocyanine (Pc) ring, or between a couple of molecular rings forming a sandwich-like structure. These materials can show electrochromic and even polyelectrochromic properties.

As an example, the green colour shown by neutral Lu(Pc)₂ can be converted to blue upon reduction or to yellow on oxidation. [3]

Table 3: Examples of organic electrochromic compounds. [4]

Conductive polymers	Viologens	Metallopolymer
Poly(3,4-ethylene dioxathiophene) (PEDOT)	1,10-Disubstituted-4,40-bipyridinium salts	Metallophthalocyanines (M-Pc)
Poly(3,4-propylenedioxathiophene) (PProDOT)		e.g. Lu(Pc) ₂
PAni		
Ppy		

Comparison between organic and inorganic materials

The comparison between organic and inorganic product have been done in Table 4. The use of organic materials in electrochromic devices has been limited, for many years, as compared with inorganics, owing to reduced values of crucial figures of merit such as stability/lifetime, response speed and coloration efficiency shown by several devices. However, more recently considerable improvements have been made and, in certain cases, organics have demonstrated better performance than inorganics

The best performing inorganic electrochromic material, namely WO₃, certain conducting polymers, such as PAni, PEDOT, as well as derivatives of PProDOT (Table 3), exhibit today higher efficiency of coloration (electrochromic efficiency).

Table 4: Comparison between organic and inorganic materials. [15]

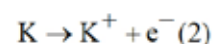
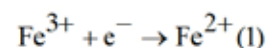
Property	Inorganic materials	Organic materials
Method of development	Needs sophisticated techniques such as vacuum evaporation, spray pyrolysis, sputtering, etc.	The material can be easily prepared by simple chemical, electrochemical polymerization and the films can be obtained by simple techniques such as dip-coating, spin coating, etc.
Material processibility	The materials are poor in processibility	The materials can be processed very easily
Cost for making the final product (device)	High as compared to the polymer based devices	Low cost as compared to the inorganic materials
Colours obtained	Limited number of colors are available from a given material	Colours depend on the doping percentage, choice of the monomer, operating potential, etc. Hence, large number of colors are available with the polymeric materials
Contrast	Contrast is moderate	Very high contrast can be obtained
Switching time (ms)	10–750	10–120

MATERIALS AND METHODS

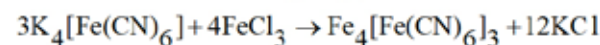
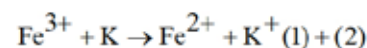
Materials

Prussian blue, an inorganic compound, has been selected in this study, due to its availability and ease of preparation by electrochemical reaction. Two precursors, FeCl_3 and $\text{K}_4[\text{Fe}(\text{CN})_6]$ have been utilized together.

The two half equations:



The global equations:



A spacer textile has been used in order to keep the electrochromic compound in a liquid phase. The spacer textile thickness can be set between 0.5 and 1 mm. When the orange coloured solution is introduced to the white spacer textile, its colour becomes yellow because of low concentration.

The upper electrode (transparent and flexible PET/ITO, from Sigma Aldrich) seals the device by using commercial glue (Magnumbond, purchased by K+S Industriebedarf GmbH).

Methods

A sandwich structure is used to build the electrochromic device. This following scheme (Fig. 1) is defined:

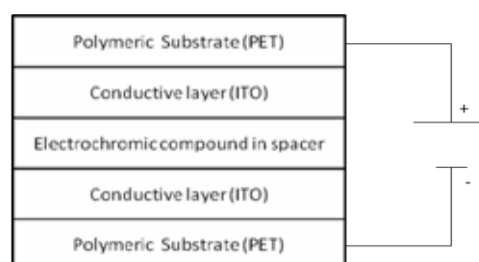


Figure 1: Five-layer electrochromic device [9]

A few millilitres of solution are introduced inside the spacer textile (2 ml of mixing/cm³ of spacer). Then, this spacer textile is put between two sheets of PET/ITO layers with conductive side on the spacer. A power supply is used for the system and generates the colour change (after few seconds).

To characterize the colour change, a spectrophotometer DATACOLOR International, Spectraflash SF600 plus model, and the L*c*h method [8] were used. To compare results, a CIELab colour space was used (Figure 2).

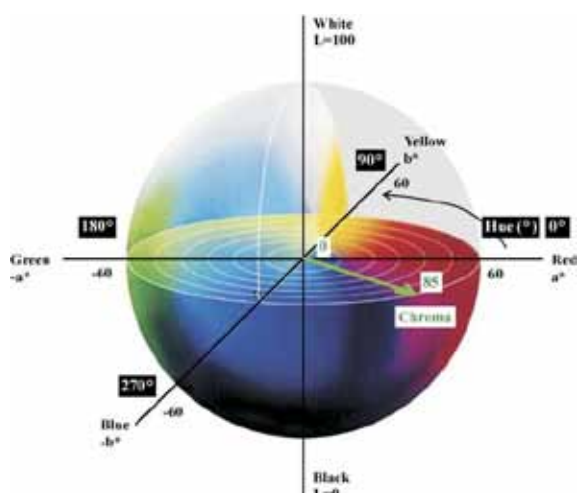


Figure 2: CIE Lab colour space [18]

Numerous measurements have been realized with different time and voltage ranges. The time to obtain value measurement with spectrophotometer is 5 seconds. A difference of h and L values between two states is observed. Variation of h value is due to the redox reaction inducing colour change. For the L value, it can be explained by the brightness difference between yellow and blue colour.

Measurements have been done only on the spacer textile, not on the entire device.

RESULTS AND DISCUSSION

A colour change from yellow to blue was obtained after 5 seconds. The colorimetric difference between these two coloured states was given by the next table (Table 2). Colours specifications have been measured at the first step and at the final step of the process.

Table 2: Results of measurement with spectrophotometer

	Colour	L D65/10	c	h
Sample before testing	Yellow	64.06	43.10	68.86
Sample after testing	Blue	30.12	36.52	243.83

The L value for different tests has given in table 3.

Table 3: Measurements of L value

	1 Volt	2 Volts	3 Volts	4 Volts
20s	62,03	65,43	69,21	67,28
30s	63,27	69,04	69,84	71,25
40s	64,52	68,62	70,94	68,04
50s	64,81	68,92	71,77	71,55
60s	65,12	69,81	74,7	78,64

Above the line inside the table, these tests have not given an important difference of L value. Below the line, the L value measurements become significant for Prussian blue.

Parameters have been chosen in relation with applications. A device containing an important power supply (high voltage) will obtain quick colour change. For a device with a nomadic battery, the colour change will be more long. Depending on the power supply and the time, this device makes for get a colour change and a dynamic effect.

If current direction is inverted, the blue colour on one face disappears and appears on the other face. This dynamics of this reaction is related to the thickness of a spacer textile. Ions available in the electrochromic liquid phase could be moved easily between the two sides of spacer textile. Up to 10 cycles of reversible colour change can be applied without observable degradation. However, a few Prussian blue particles remained on the ITO film after cycling. The device needs more time to dissolve these particles. It appears a saturation phenomenon occurs due to the product of the chemical product. This phenomenon decreases the ITO availability to bring the required current to activate the redox reaction.

The colours obtained before and after reaction have shown in Figure 3.



Figure 3: Colour change before and after power voltage

CONCLUSION AND PERSPECTIVES

A new way of using electrochromic compounds is employed with textile. Using only commercial chemical products, a five-layer structure device is created. The next step will be to deposit electrochromic products on conductive textiles. New investigations are currently undertaken in order to improve the device cyclability [16, 17]. A lot of applications (garments, upholstery, design) could be considered because of low voltage and spacer textile design ease.

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Virtual Colour: Additive Colour Mixing on Textiles with Liquid Crystal Dye Systems

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ABSTRACT

There are two types of thermochromic dye systems which change colour in reaction to temperature variation that are suitable for application to textiles; the leuco dye type (which change from coloured to colourless) and the liquid crystal type (which change through a spectrum of colours). This paper presents an illustrated discussion of selected findings from a practice-led investigation, particularly focusing on the colour change mechanisms of the liquid crystal type, and how, in principle, they can be used to produce colours by additive colour mixing on a fabric surface. The findings from this investigation are supported by initial results from a parallel investigation, inspired by the practice-led research, into the scientific basis of the additive colour mixing properties observed.

Keywords

Liquid crystals, thermochromic, textiles, additive colour mixing, design, electronics.

BACKGROUND

The research presented in this paper forms part of a broader, in-depth investigation into the potential that thermochromic dye systems offer in terms of colour change on textiles, when used in combination with specifically designed and constructed heat-profiling electronic circuitry.

The research is practice-led but is underpinned significantly by investigations based on scientific disciplines, such as electronics and colour chemistry.

Therefore, the research extends beyond 'design thinking', in terms of methods that designers adopt during the creative process, and is closely aligned to a 'designs-in-practice' approach. The 'designs-in-practice' approach [5] refers to the evolving nature of design outcomes through the process of practice, extending the concept of the design process beyond the designer to the many scenarios and stakeholders outside the design production. The stakeholders, in the case of the research described in this paper, were the collaborators who provided expertise in electronic engineering and colour chemistry. The scenarios that acted as design catalysts for exploiting the colour change mechanisms were methodological tools, such as the electronic systems applied to create constant transformation on a fabric without designer intervention.

The focus of this paper is on the findings based on the properties and design potential of the liquid crystals thermochromics. The design and construction of the electronic circuitry is not described in detail in this paper. Instead, an overview of the circuitry that was used to establish an understanding of the control mechanism involved in heating the fabrics treated with the liquid crystals is provided.

OVERVIEW OF CIRCUIT CONSTRUCTION

The Figures illustrated in this paper are all of fabrics printed or coated with thermochromic liquid crystals in contact with a star-shaped circuit and powered by a variable power supply. The star-shaped circuit was developed based on results from a series of tests to establish a heating mechanism that would create a silhouette shape (through colour change) created by heating. The circuits are termed 'heat-profiling' electronic systems because they create a profile of the heating circuit design (in this case a star shape) on the surface of the fabric.

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The heat-profiling circuitry provides a tool for visualising, controlling and mixing colour on a fabric surface.

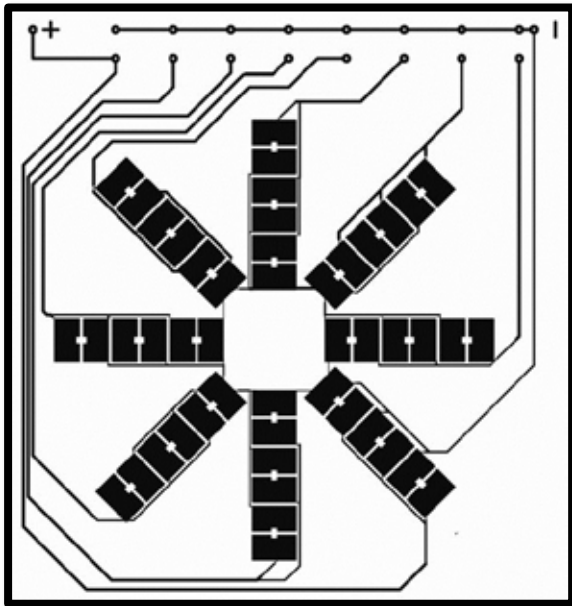


Figure 1.1 Star-shaped 'heat-profiling circuit.

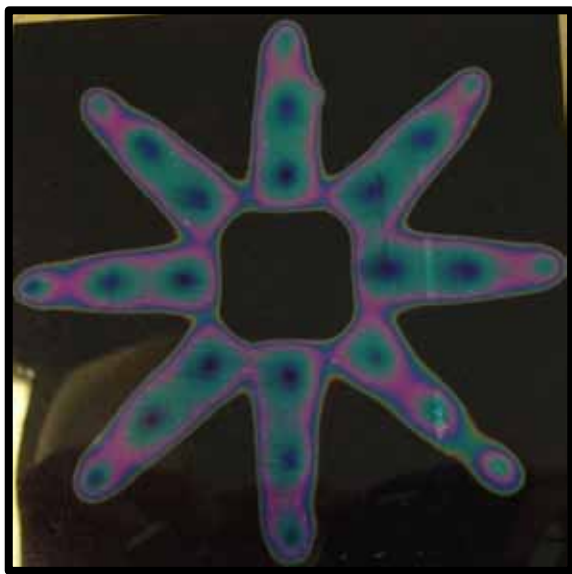


Figure 1.2 Liquid crystal colour change (showing the same combination 35°C and a 40°C as Figure 3.1)

The circuit was designed using traditional printed circuit board (PCB) technology and took advantage of the conduction properties of copper. The arms of the star are divided into three small copper heat-sinks (1cm x 1cm). Each copper shape is connected by a small resistor

(which was soldered by hand) with an external depth of 0.65mm and an external width of 1.65mm with a resistance value of 150 ohms, to generate heat flow into the copper shapes (as shown in Figure 1.1). The variable power supply allowed control of voltage, which in turn controlled the temperature profile and thus the colour changes taking place on the fabrics. In the context of this paper, this is of special importance for the activation of fabrics treated with liquid crystals with different temperature thresholds. The fabrics were laid over the surface of the circuit (which was flat) and, as the circuit heated the fabrics from below, they started to change colour and map the heat profile, generating both pattern and colour change (as shown in the example given in Figure 1.2). The star shape motif was chosen as it was the most complex shape achievable with the simple rectangular components of the heat-sink construction; it also produced an interesting organic motif [8].

HISTORICAL CONTEXT OF LIQUID CRYSTAL DYE SYSTEMS

Thermochromic systems began to appear from laboratories in the 1960s and have subsequently found use in a range of applications, from digital displays to medical thermometers. Reversible and irreversible thermochromic materials are used in a range of functional products. Irreversible colour-change paints were designed to test the function of combustion engines leaving a heat map on the mechanical parts. The indicator labels market, where colour is used to indicate temperature, is reported to be the largest for thermochromic products. Since the development of microencapsulated thermochromic dye systems, it has been found that they can be applied to a wider range of materials. However, they were not specifically designed or intended for use on textiles [8]. Rein Lemberg published the first literature on the aesthetic use of liquid crystals in 1968. The paper describes liquid crystals as responding with chameleon-like colour change and processes for the application of liquid crystals to substrates [6].

David Makow an artist and physicist began to use liquid crystals as a medium for art in 1972, after reading reports in scientific literature on their brilliant colours. Makow's abstract paintings from 1972 onwards appear to demonstrate an in depth understanding of the materials. Makow used polymers with liquid crystalline properties (PLCs), which demonstrate that different colours can be seen in the liquid crystals from different viewing angles. Makow also used free liquid crystals (un-encapsulated) and encapsulated liquid crystals on black and coloured substrates in his paintings, setting a precedent for their creative use as an artistic medium [7].

In 1974, Yves Charnay started to explore the colour, temperature and the iridescent properties of liquid crystals. According to literature reports, in the early 1980s, small pockets of artists started to work with these materials as a result of the appearance of publications on the subject [7].

MECHANISMS OF COLOUR-CHANGE IN LIQUID CRYSTALS

Liquid crystals are described as a state of matter intermediate between a crystalline solid and a 'normal' liquid. A crystal is a solid with a structure with positional and directional order, and is referred to as anisotropic. An isotropic liquid has a structure that has lost all positional and directional order. Many liquid crystals have a structure that has no positional order but retain some directional order. This means that the molecules show some orientation that, in specific cases, causes reflection of light, in a sense like crystals, giving rise in certain circumstances to brilliant colours [7]. The colour changes result from the way in which light interacts with the liquid crystals to produce coloured reflection by interference, and from the way the liquid crystal structure varies with temperature [2]. There are two types of commercial liquid crystal thermochromic dyes, which can be applied to textiles: cholesteric, based on naturally-occurring materials, and chiral nematic which are synthetic. The latter have been less commonly used for textiles, possibly because they are more expensive, although they provide superior stability and a stronger 'colour-play'. The commercially-available liquid crystals can be characterised by a set of specific temperatures. The temperature threshold refers to the initial temperature at which the colour change provided by the liquid crystal is activated. The dyes are also characterised by 'red start' and 'mid-green' temperatures and by the colour-play bandwidth, defined as the difference between the blue start and red start temperatures. The 'colour-play' is defined by specifying either the red start or the mid-green temperature and the bandwidth. For example, R35C1W describes a thermochromic liquid crystal formulation with a red start at 35°C and a bandwidth of 1°C, i.e., a blue start 1°C higher, at 36°C [4]. In general terms, the bandwidth expresses the rate at which the liquid crystals change through their spectrum of colours. R35C20W has a red start of 35°C and a blue start 20°C higher, illustrating that it exhibits its full colour play over a much broader temperature range than R35C1W.

APPLICATION METHODS OF LIQUID CRYSTALS TO TEXTILES

Bright iridescent colours can be achieved on textiles using liquid crystals based on reflection of selected wavelengths of light due to changes in the structure of the materials with temperature; however, for the reflected colours to be clearly visible, it is necessary that the remaining components of the incident light that are transmitted are absorbed. In practice, coating or screen-printing a thin layer of the liquid crystal dye over a dark, ideally black, background allows the colours to be seen at their brightest. For observation of the full spectrum of colour range a black background is particularly effective at absorbing the transmitted wavelengths of light [1]. Normally, the reflected colours observed as the temperature is raised proceeds from red, through yellow, to green and blue, eventually reverting to colourless when only the black background is observed. However, as we have previously reported, the use of coloured backgrounds can create more subtle iridescent colour effects and can enhance certain colours in the spectrum [3].

LAYERING OF LIQUID CRYSTALS

An important chance discovery was made in the initial testing of liquid crystals, in that unusual 'colour play' effects were observed when two liquid crystals with different temperature thresholds were layered by printing. Traditional liquid crystals used alone are restricted in the colour range, invariably changing from red through green to blue as the temperature is raised. This restriction could be seen to limit the design possibilities. However, in this case, the layering produced additional colours, including turquoise, lilac and purple. This result prompted a series of tests using combinations of different temperature threshold liquid crystals layered on textiles in order to explore the possibilities of creating a wider colour spectrum. A range of chiral nematic liquid crystal slurries with different temperature thresholds (from 25–60°C) and bandwidths (from 1–20°C) were provided by LCR Hallcrest, Connahs Quay, UK. The slurries were applied to selected fabrics (black brushed cotton, black wool felt, and black waxed cotton) in thin layers using a 25µm drawdown bar.

ADDITIVE COLOUR MIXING

The results observed from the coated liquid crystal fabrics used in combination the star-shape heating circuit demonstrate that it is possible to create a

wider range of colours in the spectrum through layering different temperature threshold liquid crystals. The colours that are produced appear to be similar in principle to those produced on the basis of additive colour mixing. Additive colour mixing, refers to the mixing of coloured lights, so that the source of illumination is observed directly by the eye. Subtractive colour mixing is the process normally involved when a white fabric is printed with traditional dyes or pigments. In that case, the colours observed are produced by the dyes or pigments on the fabric which is absorbing certain wavelengths and reflecting back those components of the light that are not absorbed. Liquid crystals produce colour based on a different principle. The structure of the liquid crystals causes direct reflection of particular components of the incident white light. Within the liquid crystal there is no light absorption. The components of light that are not reflected are absorbed when they reach the black background. Highly unusually, this particular mechanism of light reflection from liquid crystals means that they effectively act as primary sources of light, and thus the principles of additive (as opposed to subtractive) colour mixing come into play. The colours red, green and blue are referred to as the additive primary colours. The significance of the primary colours is that they cannot be obtained by mixing other coloured lights, but they may be combined in appropriate proportions to produce the secondary and tertiary additive colours. It is thus of particular note in the context of the research described in this paper that the three additive primary colours, red, green and blue, are the colours observed within the 'colour play' of normal liquid crystals. When liquid crystals with different characteristics, in terms of activation temperature and bandwidth, are laid down by coating or printing in separate layers, these primary colours mix to create a variety of additional colours as a result of the additive colour mixing process. For example, when applied in equal quantities, red and blue will mix to give magenta, blue and green to give cyan, and red and green to give yellow. Figure 3.1 shows a sample prepared layered with a 35°C and a 40°C (red start) liquid crystal proceeding through its 'colour play'.

It is possible to observe at least 3 unique colours arising from the additive colour mixing within this sample. The purple colour is likely to be produced by mixing of a blue phase of one temperature threshold liquid crystal with the red phase of another, with the blue being dominant. The pink may be created similarly by mixing of the red phase with a blue phase in separate layers, with in that case with the red phase dominant. The thin band of bright yellow, a colour that is usually barely visible with a single layer of liquid crystal thermochromic, is almost certainly a result of red and green phases mixing.

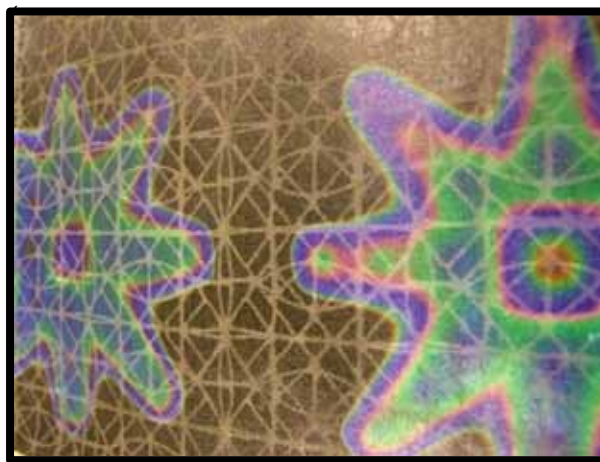


Figure 3.1: Sample of fabric with layered liquid crystals showing pink, purple and yellow and an emerald green in its spectrum.

Figure 3.2 shows a sample that has two liquid crystals layers with 32°C and 40°C red start. The more subtle colours observed are associated with the wider bandwidth (20°C) of the two liquid crystals. The cyan colour observed is likely to be due to the green and blue phases mixing.

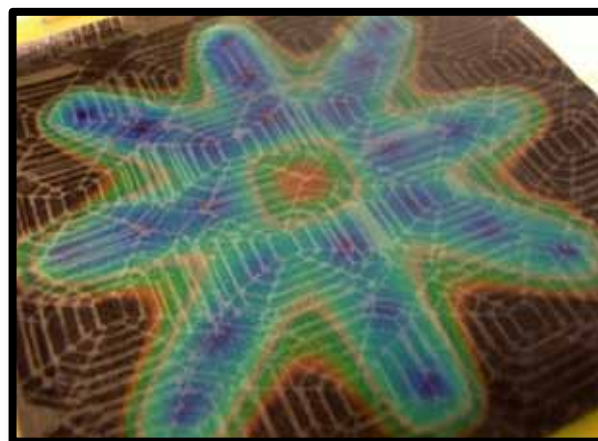


Figure 3.2: Sample showing, a pale pink, cyan, purple, green and orange.

Figure 3.3 is a fabric with two liquid crystal layers activated at 38°C and 60°C. A heat-profile (motif) of the layer with the lower activation temperature forms initially as the temperature is raised and travels through its normal 'colour play'. Bearing in mind that the temperature thresholds of the two liquid crystals are 22°C apart, as the temperature is raised further the next heat-profile forms creating a staggered colour-change response. In this case, the

38°C liquid crystal had proceeded through its full spectrum at 39°C. Hence, the second star shape (60°C) appears inside the outline of the heat-profile of the lower temperature threshold liquid crystal.

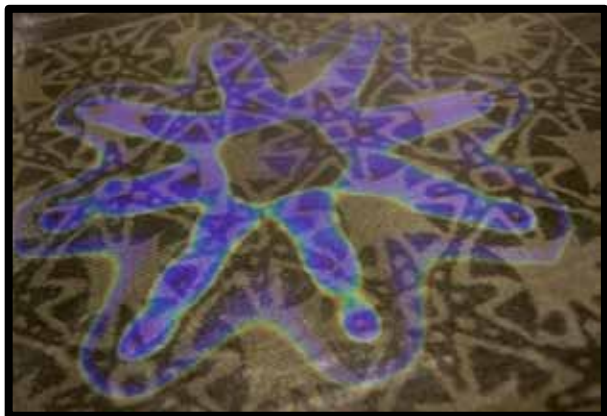


Figure 3.3: Sample showing predominantly purple and the staggered colour and pattern effect.

VIRTUAL COLOUR

The constant movement and mixing of colour created by the layered liquid crystals give the fabrics an unusual sense of life. Colour in the context of the research described in this paper is created, without the use of dyes and pigments in the traditional sense, but through combining liquid crystal fabrics with electronic ‘heat-profiling’ systems. The method of controlling colour electronically with digital input on a fabric surface suggests the conceptual idea of ‘virtual colour’. The fundamental concept of ‘virtual’ was proposed by the philosopher Gilles Deleuze, stating ‘that everything in a fixed or permanent state be superseded in favour of a constant state of becoming, where things are in a constantly changing developing state’[9]. ‘Virtual’ in this sense is not defined simply as derived from computer input, which is the common meaning of this term, but conveys rather that the virtual nature of the colour is dependent more on the structural properties of liquid crystals, the reality of which is that they are never permanent.

A METHODOLOGY FOR ASSESSING AND PREDICTING VIRTUAL COLOUR

Inspired by the additive colour mixing qualities achieved as a result of the practice-led design research, a technical investigation, currently still in progress, was initiated with a view to establishing an enhanced understanding of the physical principles of the colour formation process.

An ultimate aim of this investigation is to develop a practical methodology based on instrumentation, ideally predictive, that would give the designer the ability to select and control colour formation from the liquid crystals.

The technical investigation was thus strategically aligned with the practice-led research using the same series of specially-prepared different temperature threshold liquid crystals. This ensured that the technical results related to specific fabric samples as generated from the design research, aiming to enhance the design process.

A series of colour measurement tests were applied to selected layered combinations of different temperature threshold liquid crystals applied as coatings on a thin black transparent polyester film.

The instrumental arrangement, which was devised in our laboratory for the colour measurement of samples at different temperatures, has been described previously [2]. This arrangement for analysis consists of a programmable Linkam TH600 hot-stage, with a PR600 temperature controller, held tight against the aperture of Datacolor Spectraflash SF600 reflectance spectrophotometer. The equipment provides the double function to maintain temperature accurately and measure the colour of the liquid crystals, changing as the temperature is increased, for example at 0.5°C increments. The results of the analysis of the coated samples produced physical data which characterised the way in which the colours change and confirmed that the process involved essentially the principles of additive colour mixing. However, the investigation also highlighted the complexity of this process, the details of which will be reported in separate technical publications. Also, the investigation has provided a means to use these data to illustrate the way in which the colours change with temperature variation, by the production of detailed colour charts of each individual liquid crystal and the layered combinations that were produced and analysed. The transition of colours that the liquid crystals move through is charted, providing a visual representation of the colours achievable with particular combinations. The analysis also provides individual RGB codes for each colour produced throughout the transition over the full range of temperatures. The method thus provides a tool for the designer to establish an understanding of the colour transitions that may be provided by particular liquid crystal combinations, and the temperatures at which specific colours may be achieved. This may act as a guide to the designer in selection of the particular thermochromic liquid crystals and their combinations to produce the desired colour effects.

The RGB codes of the liquid crystal colour transitions may be imported into Adobe Photoshop either manually, or by using an automated function. Photoshop has a function that creates a colour indexation of an image; this has been utilised to transport the RGB codes from Excel, in which they were originally created, into Photoshop. Using this function it is possible to create a custom colour indexation of the specific liquid crystal combinations as shown in Figure 4.1.

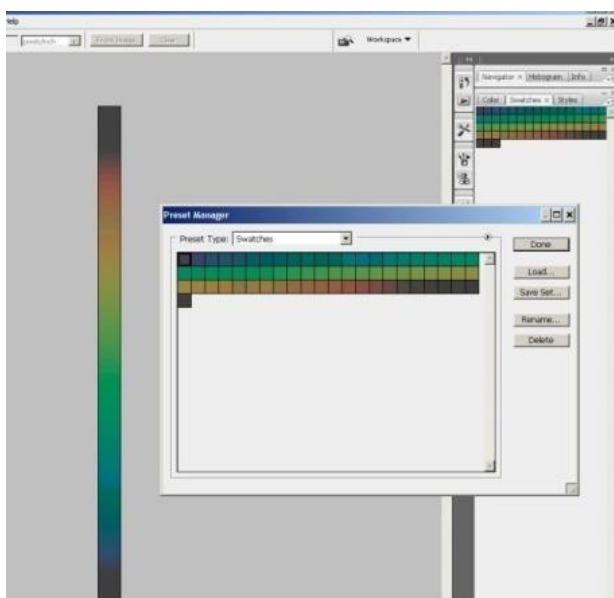


Figure 4.1 Colour index in Photoshop of liquid crystal transition.

Thus a custom colour library is produced in the swatches panel of Photoshop and these colours can be individually labelled and saved in relation to their temperature. The results from the technical investigation are therefore capable of providing a tool for conceptual design with liquid crystals. Photoshop provides a package to use data collected in the course of the technical investigation for design purposes and provides a means to simulate with accuracy the outcome when certain liquid crystals combinations are layered in terms of the relationships between colour and temperature. The indexed colours were collated in order into the gradient tool to create a custom gradient. This provides a means to visualise the liquid crystal colour gradients in a design package, for checking consistency with the original data and to begin to design with those gradients and / or individual colours.

The development of a method that facilitates the production of conceptual designs for particular applications through prediction of colour transitions of the liquid crystals may well be of special importance in encouraging exploitation in design of the unique properties of liquid crystals, especially in the area of smart textiles.

SUMMARY

Liquid crystals exhibit many exciting qualities in terms of colour, through their unique properties it is possible to create colour of a virtual nature on textiles. The use of electronic systems and digital input can generate a certain amount of control of the addition of colours. However, the dynamics of thermal energy and the complexity of the physical nature of liquid crystal 'colour play' present material challenges. Liquid crystals are full of contradictions, they change in response to temperature, however can be degraded by excessive heating and UV exposure. The notion that you can produce and predict colour that resembles that of emissive light on textiles is exciting, however the ultimate prediction tool would also give information about longevity. The concept of virtual colour in terms of smart textile design offers designers an alternative way to create colour and has to take into consideration the non-permanence of colour. This delicate phase of matter need a different design approach in terms of elements of control and the notion of colour choice. It appears that liquid crystals have hidden inspiration on the generation of responsive colour still to offer. However, as far as advances go in research both from a design and science perspective the materials will never offer the permanence or stability of traditional dyes stuffs. The applications and product areas that liquid crystals are applied need to treat this non-permanence as part of the design function.

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Understanding the Complexity of Designing Dynamic Textile Patterns

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ABSTRACT

Through a smart textile design project we have identified two sets of complex issues generally relevant for design with state changing materials. Specifically, we show how the temporal dimension of smart textiles increase the complexity of traditional textile design variables such as form and colour. We also show how the composite nature of smart textiles creates a series of interdependencies that make the design of the textile expressions additionally complex. We discuss how these forms of complexity provide opportunities as well as challenges for the textile expressions, and we show how we dealt with them in practice.

Keywords

Smart textiles, textile print, thermo chromic print, dynamic patterns, material composites, complexity, design practice, design tools

INTRODUCTION

Smart textiles, and specifically the combination of electronics and textiles, can be seen as textiles that in one way or another are able to change recursively between two or more states of expressions. They thereby provide a stronger temporal dimension to the design variables (i.e., colour, form, texture) traditionally found in textile design [7]. For that reason, the design, and the process will differ. New developments always pose new challenges, but the challenges in designing with smart textiles are not just a matter of obtaining sufficient skills in the disciplines involved (e.g. weaving, printing, electronics, programming). We have through a practical design project identified two sets of complex issues specific for designing with smart textiles. One pertains to the composite nature of smart textiles and the other to their temporal dimension.

This paper looks at how the temporal dimension and interdependencies within the composite and among the design variables affects the design of smart textiles. Through a specific experiment with a woven textile printed with thermo chromic ink with state changes controlled by a computer we discuss how these forms of complexity provide challenges as well as opportunities for the textile

expressions. In some cases, we also propose strategies, and tools, which we developed as means to manage the various cases of complexity.

The temporal dimension is a central and unavoidable design variable in, for instance, interaction design where the computer is the primary material or medium. That said it is not always dealt with as conscious variable in the design choices. In the “Slow Technology” project Hallnäs & Redström [2] pointed out how the computer’s transition from a solitary tabletop object into being embedded in every object and environment demanded an increased understanding of how the ongoing changes of expressions affects our environments. In another project, Bergström *et al.* [1] discuss how computational materials comes to be in context over time because of how their expressions changes over time quite often as a consequence of specifically contextual changes. They propose to make low-fi large-scale prototypes as a practical method to achieve an understanding of how a particular material will come into being in context over time.

In traditional textile design as well as in material science it is well established that there are interdependencies in the design of a textile or a composite material [3, 7]. Indeed, to some extent textile design can be understood parallel to the design composite materials. Every combination of materials, every design choice, enhances or enables something, and suppresses others. In textile design, for instance, the focus can be on the expression and quality of the textile whereas in developing composite materials the focus can be on developing new (combinations of) material properties. When we design smart textiles both cases of interdependencies are at play.

The following section contains a description of the practical project Recurring Patterns that forms the basis for our analyses. The two main sections contain complexity analyses, and methodological suggestions rooted in the temporal dimension and the material interdependencies respectively. The final section contains a discussion of the advantages and challenges of that these complexities entail.

RECURRING PATTERNS: PROJECT DESCRIPTION

In our current research program, we explore how and what we can design with smart textiles [4]. In this project, we had the opportunity to work with a furniture company and thus investigate some of the practical aspects of designing with smart textiles.

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The outset for the design was a weft ribbed cotton fabric, with conductive steel threads attached on the backside at every five millimetres in the weft directions using the stitching tie technique (see Figure 1).

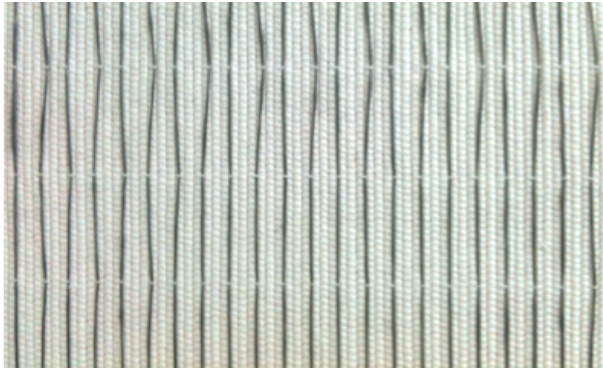


Figure 1 Weft ribbed cotton fabric with conductive threads

This fabric is intended as a canvas for print with thermo chromic ink. When running current through the conductive threads they heat up and thereby cause a colour change in the print along each thread. Thus, the design task was to develop the canvas, the prints as well as the conditions for the changes, possibly with an interactive dimension.

Ire Möbel provided two footstools as well as the expertise and manpower to upholster them with the textile we produced. We designed a different print for each footstool, as a way to explore more techniques and expressions. Both prints are made from combinations of thermo chromatic ink and pigment colour. One print is made from a magnified picture of a knitted textile, where one part of the knitted structure disappears in the heated state of the print (figure 2). The other is a collection of geometric patterns printed in a colour palette consisting of several dark grey nuances, which change into a variety of colours when heated. Some of the patterns in this print exhibit form changes when heated, and others change only colour (Figure 3).

A series of Arduino boards placed inside the footstools controls the current running through the conductive threads which caused them to heat and in turn change the colour of the thermo chromic ink. Two textile pressure sensors [5] placed one in each end enables some degree of interactivity. The setup can be configured to suit specific contexts. For the exhibitions at Stockholm Furniture Fair and at Salon del Mobile in Milan, for instance, the colour change in the footstools needed to be as noticeable as possible to attract attention. Thus, we made the textile on the one stool change colour in a looped pattern and on the other only when someone activated the pressure sensors, i.e. by sitting on it. Other situations and contexts of use may have other demands on the temporal expression and interaction.



Figure 2 Footstool with a textile structure pattern.



Figure 3 Footstool with a geometric pattern

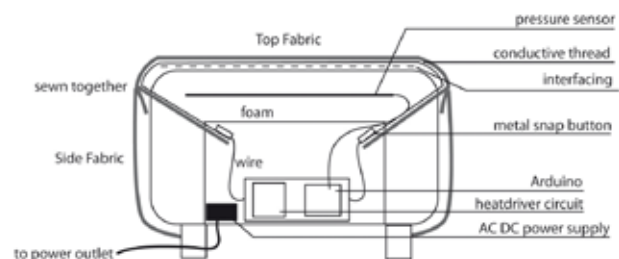


Figure 4 Illustration of the components used in the prototypes.

DYNAMIC DESIGN VARIABLES

As argued in the introduction the recurrent change of expression in this sort of smart textiles poses a new complexity to the design task. In the Recurring Patterns project, for instance, this complexity is partly seen as a consequence of the gradual transitions between the cold and the warm state of the printed expression. The conductive threads that are used to control the colour change, take time to heat up and to cool down. This gradual temperature change creates an equally gradual colour change and thereby adds shades and even other colours to the expression. Obviously, this enables a whole new range of complex expressions but it also creates a new set of considerations to the design process. Below is an analysis

of what this complexity means to the traditional textile print design variables of colour, form, and rhythm.

Colour and colour palette

For the Recurring Patterns project we used two types of colours: the thermo chromic inks, which change from opaque to transparent at 27°C, and pigment colours, which are constant and unaffected by temperature change. By mixing the two types of colours, it is possible to create a range of colour changes where part of the colour disappears, and other parts remain (i.e. going from dark grey to light blue or changing colour tone from green to yellow). Dynamic patterns based on these types of colours can therefore change between two different expressions. Worbin has described this as an alternation between two states: “a reversible pattern changes from one expression into another or several others, and always changes back to its initial expression. The pattern can also be described as A B A” [7, p. 49]. When looking at the pattern and specifically the colour mixing in Recurring Patterns project it becomes apparent that this description should be expanded to also encompass the transitions between the states of A & B. Thus, the change of colour would probably better be described as: $A \rightarrow B \rightarrow A$.

A dynamic colour can be seen as a colour scale of nuances in-between its colour at an ambient temperature to its colour at a heated temperature. Diagrammatic this could be described as $A \rightarrow B$.



Figure 5 Colour scale that gradually changes from colour A to colour B.

The transition from $A \rightarrow B$ is not just a matter of grading. The nuances in-between the end colours can be influenced by how the thermo chromic inks are combined. By mixing several thermo chromic colours with slightly different transition temperatures, it is possible to add completely other colours to the colour scale. This possibility was used in the geometric shaped version of the Recurring Patterns design. In one example the colour changes from grey to transparent, passing through several shades of magenta. An expression achieved by adding a small amount of thermo chromic magenta to the thermo chromic grey colour.

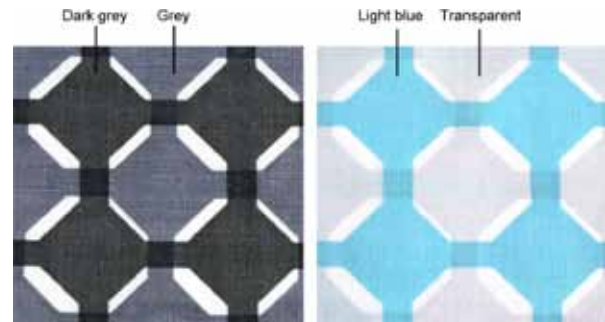


Figure 6 Left: Print sample in ambient temperature. Right: The same print sample in a heated state. Part of the pattern has changed from grey to blue, and the other part from dark grey through magenta to transparent.

The gradual change and combinatorial possibilities with this type of print create a complexity in how colours are combined in a design. Depending on how the heat element is programmed, each part of the print can be in its original state, in a heated state, or gradually changing in-between. This means that each colour added to the colour palette brings a whole range of nuances that can be combined in all possible stages with the other colour scales in the palette. At any point in time, any combination of these nuances is possible. Figure 7 describes the complexity in a colour palette with three dynamic colours, showing two possible combinations of nuances at two different points in time:

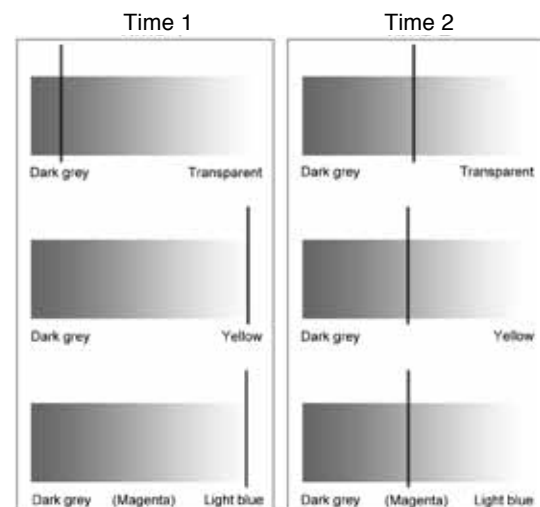


Figure 7 This schema describes the complexity of a three colour palette by showing two possible combinations of nuances at two points in time

In the prototypes constructed for the Recurring Patterns project reaching the transition temperature only took ten to twenty seconds, while the cooling down would take several minutes. Thereby causing the longest period of time the surface was changing to be when it was cooling down. The nuances that are in-between the fully heated and cooled colours therefore provide a significant visual aspect of the overall expression.

With this complex colour variation, designing the colour palette becomes rather challenging. Essentially because as soon as more than a few colours are at play it becomes difficult to grasp how each possible combination will work together. In the process of designing the Recurring Patterns sketching the colour palette by hand or on computer was therefore, almost completely, replaced by mixing colours and testing prints in the printing lab. By placing different combinations of samples together and study how they changed under the heat from a blow dryer we were able to make the selection of colours.



Figure 8 Left: Colour palette sketch, with TC colours in various stages between heated and cooled. Right: Notes describing colour-mixing tests.

Form and pattern

When working with dynamic patterns it is not only colour that can be temporal, form is also a dynamic design variable: “a dynamic form could implicitly contain all sorts of conventional forms as it varies from time to time, at one moment it displays one geometric structure, later it changes into another, and so on.” [7, p. 266]

How each form element will behave when heated, affects the expression of the design and specifically its relationship to the surrounding forms in a composition. By combining forms that disappear, change colour, or stay the same, it becomes possible to design a pattern where the relationship between elements in the composition changes at different temperatures. The considerations needed when designing a static pattern are still relevant when designing dynamic forms and patterns, but they are multiplied. It is no longer just about building up one composition of forms but about building up compositions of compositions of forms.

Figures 9-11 are prints made in the Recurring Patterns project, which illustrate how the relationship between the shapes in the design can change when the surface is heated. Figure 9 and 10 show how the same combination of forms changes in different ways depending on how the thermo chromic ink and pigment colours are placed in the composition of the pattern.

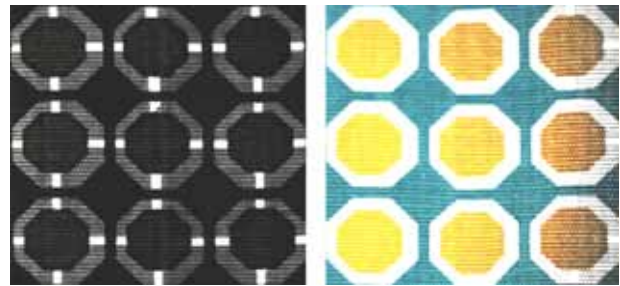


Figure 9 The first version of the same combination of forms. Left: shows the pattern in ambient temperature. Right: shows the pattern has been heated.

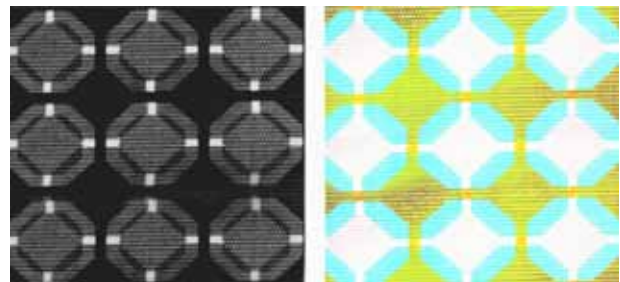


Figure 10 This is the second version of the composition in an ambient and heated state. (The forms are the same in both prints but print colours are different, the two versions are therefore slightly dissimilar in ambient temperature.)

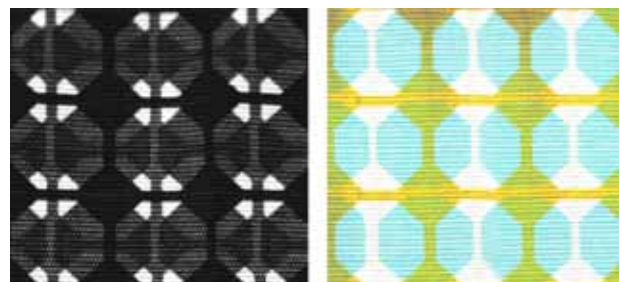


Figure 11 Left: Print sample in ambient temperature. Right: Heated print sample.

When one area changes that will have an influence the expression of the rest of the surface. Working with a textile that can be programmed to heat up sections independently means that at any given time is it possible for each part of the surface to be in its ambient state, in its heated state, or somewhere in-between. This type of complexity makes it possible to play with the relationship between shapes, both in the small area where the heat change takes place but also in relation to the printed surface as a whole. Examples of how this possibility can be used to transform the overall impression of a pattern can also be seen in Worbin’s project “Textile displays” [7] where the prints go from repeated to placement print by changing how the heating elements behind the textile are programmed.

To design a composition of compositions can obviously be difficult to do without the right tools. The design of the geometrical pattern for one of the footstools (See Figure 12), was the done by extensive sketching with simple CAD

programs but primarily by sketching directly in the printing lab. Nonetheless, the complete expression was not really understood until the printed fabric was put together with a heating sequence in the final prototype. The lack of overview and the numerous combinations of changes meant that it was close to impossible to actively design every expression with the tools at hand.

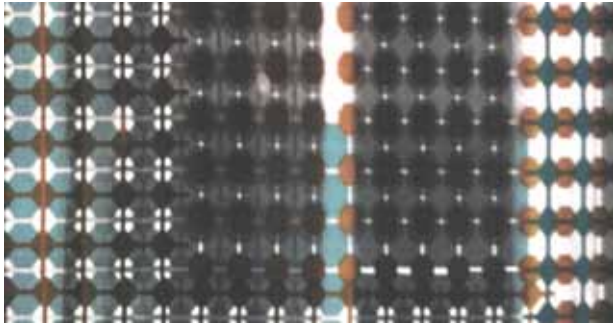


Figure 12 Geometric pattern, showing several types of form-changes occurring on the same print.

One way to reduce the complexity of the dynamic pattern is, of course, to reduce the number of combinations. By using only a few shapes and work with the same change in all areas of the surface the design tasks need not be any harder than traditional pattern design. We used this strategy in the design of the “textile structure” pattern, where the colour scales and shapes were combined in the same way all over the surface.



Figure 13 Textile structure print with one type of form change.

Sketching tool

When developing ideas for the patterns, we needed a way to quickly evaluate their transitional expression in the exact way they would happen in the final prototypes. We therefore developed a physical sketching tool from a piece of the cotton fabric with the conductive threads, a driver able to control up to ten threads, an Arduino board, and a max/msp graphical interface. This combination made it relatively easy to program the heating sequences on the Arduino board. This tool enabled us to print sketches on fabric and immediately see how they would work with different types of heating sequences. The size of the tool meant that it still was not possible to grasp the whole expression of a pattern, but it made it significantly easier to become familiar with the dynamic expression in the sketches.



Figure 14 Left: The Sketching tool is used to evaluate printed pattern sketches directly in the printing lab. Right: Printed samples would be placed on the heat element, to see how they would change when heated.

Time & rhythm

Traditionally, textiles are given their final expression in the making (i.e. during weaving, felting, or knitting), and in after-treatments (i.e. by printing, shrinking, or dyeing). The expression of a dynamic textile pattern, on the other hand, can be created and re-created through the program controlling the dynamics of the pattern or by making the dynamics dependent on contextual factors that can be sensed [1]. Indeed, the temporal dimension not only influences the design variables colour and form it also calls for the specific design of a temporal form—a rhythm. Even if the temporal form is made dependent on some kind of contextual change, the responding expression is still to be designed. Designing the temporal form becomes complex because it happens over time—we cannot in one moment see what will happen in the next, but more important because the heating and cooling does not happen in an instant the temporal expressions might overlap and thereby create new unpredictable combinations. Moreover, here we have even left out the cases of making the changes contextually dependent which adds a whole new layer of unknowns to the design process.

The heat sequence in a dynamic pattern is built up from a number of individual surface layouts (See figure 15). The composition of each individual layout is determined by the positions, sizes, and intensities of the heated areas. A new surface layout can begin even if the sections are still in different degrees of cooling. The expression as seen at one point in time, is therefore, likely to be a combination of large number of different size and placement designs.

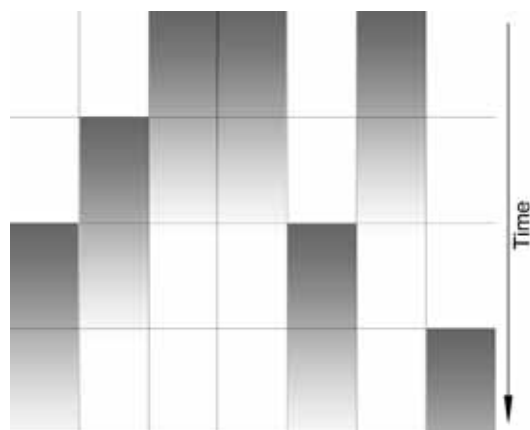


Figure 15 illustration of how the layout of the heating overlap in a composite with 7 individually controlled heat elements.

In the Recurrent Patterns project it was possible to heat the surface in 40 individual stripes. Each stripe could be turned to full heat for a few seconds at the time and each used a couple of minutes to cool down. Again, the combinatory possibilities are staggering, but design is not necessarily mathematics and a significant number of combinations might be ruled out simply because they do not look good. Thus, before we started to sketch the temporal patterns we needed to see what the changes actually looked like. For example, we studied different intensities of changes occurring all over the surface at once as well as changes growing from one end to the other.

After gaining some familiarity with the possible expressions of the temporal patterns we needed a way to sketch and discuss the layout of the temporal pattern. For this, we developed and used combination of a “music sheet” and a graphical interface to the programming of the pattern.

Sketch tools for the heating sequence

The sketch tool for the heating sequence became a combination of a “music sheet” where it was possible to mark the heating of specific sections and still keep track the previous and the following layouts. It was, however, not really possible to depict the intensities and thus the overlaps of expressions. So in a sense it is comparable to sheets of music; it still takes a skilled player to interpret the notes successfully. The graphical interface made it easy to transfer the sequences from the sheets to the Arduino controlling the heat and thereby to rapidly test or merely adjust the temporal forms.



Figure 16 Left: the graphical interface to the computer programme. Right: the sheets used in the heating sequence design process.

INTERDEPENDENCY

Interdependencies are the other aspect that gives rise to practical as well as conceptual complexity when working with smart textiles. In the Recurring Pattern project we identified what makes sense to talk about as two areas of interdependencies even if they, to some extent, also influence each other. One is found in the composite form of the material, and the other in the combination of the dynamic design variables and their corresponding complexities. The following text describes the two areas of interdependencies further by giving examples from the project.

Designing the composite

In any composite material, the material properties are not just the sum of its component's properties. Instead, they represent the result of a delicate negotiation between restricting some properties and enabling others [3]. Indeed, in this negotiation often enabling or enhancing one material property will directly restrict another. If the outset is seen as a tree of possibilities each choice will cut off a branch and its sub-branches. Hence, the consequences of a choice can sometimes be difficult to judge in advance. A smart textile is inevitably a composite material and thus also inherits this interdependency in its design.

In this case, the main components of the composite are a woven cotton textile embedded with steel yarn, a pattern printed with thermo chromic inks and pigment colour, a microcontroller on an Arduino board, an array of mosFETs as the driver circuits, and a computer program. One example of the interdependencies that we encountered while developing this composite is the relation between the conductive thread, the cotton yarn, and the sensitivity of the thermo chromic ink (which reacts at 27 °C). The conductive thread attached to the woven cotton using the stitching tie technique should be able to produce enough heat in the fabric to reach the transition point of the thermo chromic ink. Furthermore, the material, which constitutes the primary part of the fabric, should be susceptible to the thermo chromic ink as well as be resistive to the concentrated heat produced in the threads. The material

should also be dense enough to insulate the conductive threads yet permeable enough to let the heat through. Moreover, the quality of the material still has a strong influence on the durability and expression of the finished textile and thereby for which purpose it is suited.

Another example is the combination of a computer and a textile. Separately they can be used in innumerable ways. In unison they restrict each other's potential, but simultaneously enable completely new expressions. More specifically, the textile must be able to express at least two states to accommodate the temporality of the computations and the computer program must be restricted (programmed) to effectively express something specific in the textile. In *Recurring Patterns* the computer is programmed to control the switches on the array of mosFETs, which in turn control the flow of current through the specific lines of conductive threads.

The strategy used in the *Recurring Pattern* project was to develop the composite starting with one material element and then gradually adding others. This strategy made it possible to understand the consequences of each new addition, and therefore to relate the new potential to the choices already made. In this case, the woven fabric with the conductive threads served as the starting point. The linear layout of the heat elements, for instance, became a strong signifier for the later design of the print layout. The downside of this strategy is that the resulting material composite could perhaps have accommodated the desired purpose better if some of the choices made in the beginning were kept open till the end.

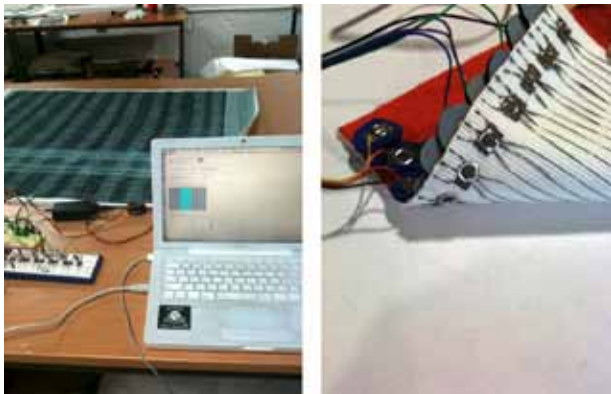


Figure 17 Images from the composite design process.

Designing the textile print

The design of the textile composite combined with the complexity within each of the dynamic design variables also increases the complexity when composing the overall expression. Here demonstrated through two examples.

Traditionally, the design of form and colour consists of a series of interdependent choices at least when the form is expressed through the colours, for instance, some colours appear to be in the foreground when combined with their contrast colour. When designing with dynamic colours, and

through those dynamic forms, makes it is possible not only to change the forms and colours, but also to change the relation between the forms. For example, where one form may appear in the foreground before the colour-change it may have shifted to the background after the change. More generally, the colour palette will simply regulate the forms and their transformations and vice versa.

Another example is about how the layout of the heating elements will have a significant impact on the way each form can change. In the textile composite for *Recurring Patterns*, the heat elements can warm up sections of 20mm wide stripes over the width of the fabric. Obviously, this places some constraints on how the forms can change. We could either use it as an element in the pattern or find ways to hide it through the composition of the forms. Another challenge was in the distribution of a pattern over more than one heat element. When, for instance, a form was placed over two different heat elements it could also be transformed by both. This meant that the same form could either be completely changed, half changed, or remain unchanged depending on the temporal pattern. Thus, the form compositions are also dependent on the temporal forms and vice versa.

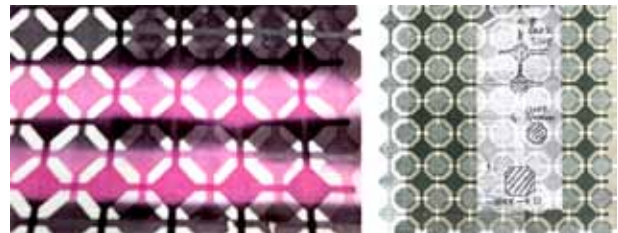


Figure 18 Left: A printed sample placed on the sketching tool with two heat elements activated, the line shape of the heat element has a strong effect on the expression of the change. Right: A printed sketch of how form and colour could be combined. The notes on the sketch describe how the different forms react to heat.

When designing textiles, sketches are often done on paper, with CAD programs or directly on fabric. In this case, such techniques only took us so far, partly due how the interdependencies among the design variables was difficult sketch. When designing the dynamic print, doing test directly on the materials and evaluating them on the sketching tool became a way to better grasp how the combinations of colour and form worked in relation to the layout of the heating elements. The sketching tool became a way to see how the dynamic variables influenced each other already in the process of designing the pattern.

Discussion

Through this project we have identified a series of practical as well as conceptual complexities that arise when designing with such state-changing materials. Moreover, these materials are interdependent compositions of several material elements.

Some of the complexities can be turned into powerful expressions if they are mastered sufficiently. The question is how to master them. We have proposed some ad-hoc strategies and developed some sketching tools whose principles at least could be transferred to other projects.

Yet, there is a special issue which we haven't yet addressed, namely, the fact that most of these smart textiles are made for a specific project and thus to a large extent will always be novel in the design process. In traditional textile design it is possible to become really skilled in certain techniques, but the same is difficult to achieve for these smart textiles, as they are rarely mass-produced. Experimenting with the properties and potential of the smart textile at hand will therefore be a significant and time-consuming part of the design process, especially if the smart textile is also open to be changed in its composition.

Nonetheless, we do believe it is possible for textile designers to achieve some level of familiarity with the dynamics of the classic design variables, when it comes to textile prints. We do believe that identifying some of the complexities can be a start to better understand the design space these materials afford. And we do believe that with some effort and after other iterations it is possible to develop more general sketching tools and strategies to aid the designer through the design process.

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Interaction-related Properties of Interactive Artifacts

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ABSTRACT

Over the years, several attempts have been made to describe properties of interactive artifacts and/or interaction. However, these attempts tend to describe more than one aspect, e.g. combining artifact properties with aspects of the user's experience and/or with aspects that arise in use. Or, authors have focused on a small subset of qualities, or very overarching or very domain-specific qualities.

This is an attempt to describe *only* interaction-related properties of interactive artifacts in themselves, i.e. explicitly focusing on what can actually be inscribed into an interactive artifact (as opposed to what the user may experience, or what may happen during interaction). The aim has been to extend the interaction designer's vocabulary, providing a means for discussing, analyzing and comparing the interactive aspects of things. The collection of properties is comparably extensive; it contains 30 properties related to six different categories: Interaction; Expression; Behavior; Complexity; Time and Change; and Users. It can be used in several ways – to analyze and discuss properties of an artifact, as a checklist during design, and lastly as a design tool – what happens if we start out with an artifact and then change the attributes?

Keywords

Interaction, properties, artifact properties, interaction design, design tool

INTRODUCTION

Talking about interactivity and interactive artifacts is at times a complicated affair, since there are so many aspects of interaction, and so many types of interactive artifacts. As for artifacts, it can be anything more or less “intelligent”, i.e. with a programmed behavior, e.g. web services and other software applications (text editors, email programs, online calendars, digital games etc.), interactive toys, digital cameras and smart phones etc. As for interactivity, there are the interaction-related properties of the artifact itself, the ones that are explicitly inscribed – coded – into the artifact (e.g. how information is shown [16]), there are

properties that arise in use (e.g. rhythm [24]), there are properties that arise as a combination of the artifact's properties, the context of use and the user's state of mind and general predisposition (e.g. surprise [25]). Additionally, one can focus on different levels of detail, either looking at how the shape and performance of different input tools affect interaction [7], or cover all the building blocks in one specific type of application, like the buttons, menus and error messages of a GUI (e.g. [4]), or one can visit the other end of the scale and talk about aesthetic interaction qualities [24] – a very high-level concept.

This paper attempts to cover yet another aspect, looking at those very properties that together constitute how the *artifact in itself* interacts and which interaction it allows; what it “does” and is, what it allows the user to do with it, and how it reacts to user input, i.e. properties of interactive artifacts that are

- Related to interaction: *how the artifact interacts* with the user, but also in which ways the artifact *lets the user interact* with it
- *Explicitly inscribed in the artifact* (as opposed to appearing in interaction)
- *Related to over-arching design decisions* (as opposed to details regarding exactly which kind of input device to use)

Together, this collection of properties can be seen as an extended design vocabulary. The artifact-centric approach of it is deliberately chosen since it explicitly deals with the properties that we as designers de facto choose and control.

BACKGROUND

There is a need for an interaction design language, for tools that help us analyze and describe the artifacts we create. This need has been expressed explicitly by many, especially in the growing number of pattern collections related to various aspects of interaction design and gameplay design (cf. [2], [3], [9], [29]), and the different attempt to establish frameworks on different levels of design (cf. [1], [4], [11] and many more).

But – when it comes to describing *interaction in itself*, and aspects closely related to it – like how to design specific aspects of it – there are fewer texts. Lim, Stolterman, Jung and Donaldson [16] have defined “an initial set of

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attributes which can form various interaction gestalts.” These attributes are descriptions of how the interaction gestalt manifests itself, i.e. what appears in use. In all, there are eleven attributes, all related to one or more of the key factors time, space and information. The attributes are as follows: *Connectivity* (independent – networked); *Continuity* (discrete–continuous); *Directness* (indirect–direct); *Movement* (static–dynamic); *Orderliness* (random–orderly); *Proximity* (precise–proximate); *Pace* (slow–fast); *Resolution* (scarce–dense); *Speed* (delaying–rapid); *State* (fixed or changing) and *Time-depth* (concurrent–sequential). The idea is “to bring into interaction design the traditional design way of thinking and manipulating the attributes of what is designed.” (Lim et al 2007, p. 249) The idea is that the designer can start out thinking about the design of the interactions per se, without considering their physical or graphical form first. When considering artifact properties this taxonomy is somewhat problematic, since many of the attributes are dual, covering both – or either – what the artifact and/or the user does. For instance, *Movement* is described as: “The level of movement dynamics for both users’ manipulating interface elements and artifacts’ showing information elements.” Others, like *Pace*, seem to occur in use. In a following paper, Lim, Lee and Lee [17] refine and somewhat alter the list of attributes and combine them in a small application for testing, leaving only six of the original attributes (somewhat changed), and adding the new *Expectedness* (expected–unexpected).

Löwgren instead addresses the issue by describing use qualities [21], later called experiential qualities [21, 22], later refined even further to aesthetic interaction qualities [24]. As the names indicate, these qualities are related to what a user experiences when interacting with an artifact. Together with Stolterman, Löwgren created a much-quoted list of these qualities [25] divided in five groups: *Motivational qualities* (Anticipation, Playability, Seductivity, Relevance and Usefulness); *Interaction qualities* (Pliability, Fluency, Immersion and Control/Autonomy); *Qualities of sociality* (Social Action Space, Identity, Personal Connectedness); *Structural qualities* (Transparency, Efficiency and Elegance); and lastly *Qualities of meaning-making* (Ambiguity, Surprise and Para-functionality). Although most of these do focus on experience in relation to interaction, some are, confusingly enough also properties that can be explicitly inscribed in an artifact, like *Control/Autonomy* and *Anticipation*. Then again, the thought behind the use qualities is that they provide “proposed tools for questioning, elaboration, and making informed choices” ([25], p. 104); they are not meant to serve as a checklist for evaluation, and they are not a complete taxonomy, especially since they can be interdependent in several complex ways. Similarly, Wright, Wallace and McCarthy [32] suggest a framework for experience centered design, by focusing on user experience and meaning-making, and

by aiming for a holistic experience encompassing sensual experience, emotional experience, spatio-temporal experience and the narrative structure of the experience. Vensween et al [31] on the other hand, focus on the intersection between (inter)action and function and its relation to feedback.

Unlike any of the above-mentioned authors, Landin [14], looks into overlooked and unintended aspects of interaction, such as anxiety, suspiciousness and more. One of Landin’s key concepts is interaction form, which is “the way in which a design relates interaction (what you can do with a device) and function (what the device can do for you) to each other.” Examples of the forms Landin describes are for instance fragile, changeable, magical, illusionary or indistinct forms. The fragile form for example, is a result of a breakdown between interaction and function, e.g. when a computer crashes, or the fact that a web page may look and work very different depending on what browser and plug-ins you’ve currently got installed.

Whereas the above mentioned texts discuss a wider perspective of interaction design, encompassing many different types of artifacts, there are more texts covering interaction design of specific types of artifacts. Rullo [27] has explored ambient computing systems, and listed what she calls soft qualities of interaction, which are related to interaction dynamics such as access, separation/interpenetration, interferences, varying visibilities, overlapping, layering etc. Vedel Jensen, Buur and Djajadningrat [30] have instead explored movement by analyzing products in terms of interaction styles, and by applying Laban’s denotations of movement (cf. [13]), encompassing factors like weight, flow, space and timing. Similarly Djajadningrat et al [6] suggest three important factors affecting aesthetics of interaction; interaction patterns, richness of motor actions (e.g. complex gestures as opposed to monotone clicking) and freedom of interaction (many ways to do the same thing. Hallnäs and Redström [10], on the other hand, discuss interaction in terms of acts; distinguishing between what we do, how and why. Acts are seen as entities that shape interaction sequences.

In addition to these, there is an abundance of books discussing the design of different types of interactive artifacts (graphical user interfaces, web interfaces, tangible interfaces, “smart things” and so on), all to some extent covering or touching upon interaction-related properties as well as many other aspects. A typical example would be Cooper et al’s “About Face” [4] which describes design of GUIs down to the smallest detail – the choice of checkboxes vs. radio buttons – however also discussing the development process and overarching principles for layout, graphical design and usability. Similarly, most pattern collections (cf. [2], [3], [9], [29]) cover aspects on many different level; down from the smallest detail to overarching concepts.

To summarize, there is a need to extend the current design language with terms that describe interaction, and whereas all of the abovementioned sources are valuable, helping us understand aspects of interaction in itself, user experiences, and design of interactive systems, there is currently no collection of those properties that are common for all interactive artifacts, and affect interaction directly. Looking at properties on this level has been done before within game design, where the most basic level of game rules are expressed as mechanics (see the Mechanics-Dynamics-Aesthetic-model as described in [8] and [15]); similar to artifact properties, mechanics of a game are *established before use*. Drawing this line helps us establish the properties over which a designer has control, and thus neatly sets the scope of the vocabulary.

INTERACTION-RELATED PROPERTIES

Emanating from the idea of mechanics, and the need for a taxonomy describing factors relevant when designing for interaction, a list of 30 interaction-related properties of interactive artifacts has been collected. Again, the goal has been to describe properties which are

- Related to interaction: *how the artifact interacts* with the user, but also in which ways the artifact *lets the user interact* with it
- *Explicitly inscribed in the artifact* (as opposed to appearing in interaction)
- *Related to over-arching design decisions* (as opposed to details regarding exactly which kind of input device to use)

The list of properties draws from many of the abovementioned works as well as from established notions within interaction design. These notions have been collected, analyzed and iterated, used in design exercises (which served as an especially valuable source of information), discussed with students and colleagues. Once the list of properties had been established, suitable categories were populated in an iterative process. Then, the categories were examined for missing properties, and some properties were also moved between categories.

The properties are currently divided into six categories, based on the main areas of interest in interaction design; Interaction; Expressions; Behavior; Complexity; Change and Time; and Users. Since the objective is to create a way to categorize and talk about these properties, they are described as having different states. Most properties range from one state to another, sometimes with suggested intermediate states, e.g. the property *Predictability* (to which extent the user can foresee how the artifact will respond) ranges from *predictable* to *learnable* to *surprising* to *unpredictable*. It is important to realize that there is no judgment related to the states; one is never “the correct choice” whereas the other(s) is faulty. In the *Predictability*-example for instance, *unpredictable* can be a desired state too, e.g. when designing a game or an artistic application.

References to the work(s) a property is based on, has been placed as footnotes in order to avoid a cluttered text and still have the references fairly close at hand. Mentioned artifacts are listed in the References-section.

The order the properties are presented in, is not a ranked order; instead related properties are described in sequence if possible. A summarizing table of all properties, this time in alphabetical order, can be found in the Discussion.

Properties Related to Interaction per se

These properties are related to shaping interaction per se. They deal with overarching properties related to Löwgren’s concept of *Fluency* [21, 23]; how smooth interaction is, how easily we can find a path to what we want to do, how easily we can switch back and forth between tasks. They also deal with how hands-on and precise interaction is, in this covering Löwgren’s *Pliability* [22, 24]. Moreover they deal with more prosaic aspects, like input modalities, and types of feedback.

Input modalities: This property describes with which devices input can be made, including sensors.

Interaction flow¹: This property describes the fluency of interaction, and ranges from *continuous* to *discrete*. An example of discrete interaction is pressing a button every once in a while, as when reading an e-book, turning pages, whereas an example of continuous interaction would be constantly tilting one’s iPhone in various ways to guide one’s creature through the labyrinths of *Spore Origins*. However, some artifacts are also modal, which tends to break flow, e.g. switching between drawing tools that work in different ways in drawing programs, e.g. using one tool to draw a shape, another to edit it, a third to move it etc. Whereas this sequence of interaction may appear more or less continuous, the flow of it is still interrupted by the switching of modes, meaning that being *modal* resides somewhere along the discrete-continuous-scale.

Directness²: This property deals with how “hands on” interaction is. It ranges from *real-world manipulation* via *direct manipulation* to *indirect manipulation*. Real-world manipulation is related to interacting with physical artifacts, e.g. playing with one’s *AIBO* robot dog, whereas direct manipulation relates to the manipulation of screen-based items, where one operates on the object in itself and thus instantly gets visual feedback, e.g. dragging or dropping an icon, or resizing a drawn symbol – as opposed to choosing coordinates in a menu, or entering a wished percentage for size-change in a text box, which is indirect.

¹ *Interaction Flow* is a slightly updated version of Lim et al’s *Continuity* [16], lending a little from the *Flow*-concept [5]

² *Directness* is closely related to Löwgren’s *Pliability* [24]. It also lends from the GUI-design concepts of direct manipulation and indirect manipulation [4], and from Djajadiningrat et al’s ideas on richness of motor actions [6].

Freedom of Interaction³: This property is related to in how many different ways one can attain a certain outcome. It ranges from *forced* to *free*, where forced is a rigid series of steps (e.g. an install wizard) and free means that there are several paths to a certain result, e.g. playing and winning a game, or writing and formatting a paper for interact 2011.

Precision⁴: This property describes the level of precision one has in input. It ranges from *proximate* to *precise*. Using a mouse when interacting with a screen-based interface is quite precise, as opposed to interacting with the same interface via a touch screen, which is more proximate. Likewise, entering one's age in terms of years is proximate, whereas entering one's exact birth date is more precise.

Tasking⁵: This property describes whether the artifact allows for concurrent tasks. It is either *multitasking* or *singletasking*.

Properties Related to Expression

Expressions, as discussed by Hallnäs and Redström [10], Landin [14], and Lundgren [18] is any ways in which the artifact expresses itself; appearance, sound, etc. Strictly speaking, behavior is a form of expressions too, but they have been placed in their own category. The properties in this category affect interaction, since they are related to how – and how well – the user interprets the artifact's behaviors and functions, and how they navigate through the functions.

Output modalities: This property describes with which devices output is made, as well as their modalities, most commonly *vision modality* (text, graphics), *auditory modality* (sound) and *tactile modality* (touch, e.g. force feedback). It can be *singlemodal* or *multimodal*. Most smart phones are multimodal, combining not only a visual interface with sound output, but also vibrations. When playing *Blowfish* on the iPhone for example, the output when one's blowfish is being inflated by a sea urchin is three-fold; it is visual in that the blowfish shrinks and lets out air bubbles, audible in that a "pang!" sound is heard, and tactile in that the phone vibrates.

Presentation⁶: This property is related to the richness of information that is being presented. It ranges from *scarce* to *detailed*. This applies both to the information in text (e.g. a full *Wikipedia* article being detailed and a stub being scarce) but also to information visualization (e.g. a table of data pairs (scarce) instead correlated in a diagram with additional information on trends (detailed), or the level of details with which an interface expresses what is going on

and what can be done (*Windows 7* being rich as opposed to the scarceness of *Windows 3.11*).

Clarity⁷: This property deals with how clear an artifact's output or appearance is. It ranges from *distinct* to *ambiguous* and is related to any kind of output or information, from information in texts, to the layout of components (communicating what it "does"), or feedback responses. A distinct output is e.g. stock reports as text and numbers, as opposed to the faint glow of the *Ambient Orb* whose color responds to changes in the stock market.

Feedback: This property describes the different aspects of feedback. It ranges from *rich* to *poor*, and can also be described using terms like *modal*, *modeless*, *post-action* and *pre-action*. Feedback can be *modal* vs. *modeless* [4] (modes here referring to modes in programs); an example of modal feedback is a dialog box that interrupts flow to ask for input, whereas modeless feedback is given without interrupting the user, e.g. underlining words that might be misspelled. Feedback is almost per definition post-action; it occurs as a result of what the user does. However Wensveen et al [31] and Djajadiningrat et al [6] have introduced the concept of *feedforward*, which they define as "communicating what will be the result of an action." e.g. showing a preview of how something will turn out, i.e. pre-action. Navigation is another aspect of pre-action feedback; we know that if we press a link on a web page it will take us elsewhere.

Information order⁸: This property describes how information is ordered. It ranges from *linear* to *scattered*. Here, linear indicates that the order in which information is given matters greatly, as in a text or in a wizard. Scattered, on the other hand indicates that information can be digested in any order, and scattered information can thus be *hyperlinked*, or *multimodal*. The (main) information order of one *Wikipedia*-entry is linear, but the entire amount of information on *Wikipedia* is scattered.

Properties Related to Behavior

Behaviors consist of a series of expressions (cf. [10], [14], and [18]) like graphics and sounds, that indicate what can be done with the artifact and how it reacts. That there are artists to choose from in *Last.fm* is an expression, whereas *Last.fm*'s ability to link one type of artist to another, and play it too (e.g. playing Bruce Springsteen and Bon Jovi in relation to Bryan Adams), is a behavior. Thus these properties describe how an artifact relates to users, how it

Freedom of Interaction is a concept introduced by Djajadiningrat et al [6]

Precision is a combination of Lim et al's *Proximity* and *Resolution* [16], however only dealing with manipulation. *Tasking* has been suggested by Peter Lundblad.

Presentation is a combination of Lim et al's *Directness* and *Resolution* [16].

⁷ *Clarity* is related to Landin's ideas on distinct and indistinct forms [14], to Lim et al's *Directness* [16] as well as to Löwgren and Stoltermans *Ambiguity* [25] as well as Gaver et al's thoughts on ambiguity in general [8].

⁸ *Information Order* is a combination of Lim et al's [16] *Orderliness*, and some suggestions by Ruxandra Teodoru, now dealing solely with information.

behaves towards them, i.e. what it lets users do, and in which manners it responds.

Approach⁹: This property describes which interactive stance the artifact takes towards the user. It can be expressed on a scale from *submissive* via *suggestive* to *dominant*. Most work tools are submissive. They wait for the user to take action first, and then react. However some artifacts also suggest things; most email-programs suggest possible recipients on the typing of a few letters. Another example is *Last.fm*'s service to suggest new music to the user based on what the user currently listens to, and likes. Many solitary games are dominant, prompting the user to take action, *Tetris* being an extreme example with its ever falling pieces.

Level of dependency¹⁰: This property describes how much interaction the artifact requires. It ranges from being *autonomic* to being *dependent*. Autonomic artifacts carry out a task as defined by the designer or user, one example being automatic vacuum cleaners like the *Roomba*, which requires very little attention from its owner. Another example is a music player that, once a playlist is started, will go on playing it until it either ends or the user stops it. Most artifacts can be seen as quite dependent since they depend on the user to do something in order for them to take the next step in the user-artifact interplay.

Forgiveness¹¹: This property describes how forgiving an artifact is towards the user's mistakes. It ranges from *forgiving* to *unforgiving*. A software with many levels of undo and file-recovery is very unforgiving, whereas many games are unforgiving which in that case contributes to the Difficulty of the game (see below).

Robustness¹²: This property is related to the artifact's ability to cope with unintended use, misuse or abuse before they break down, or start doing something the user did not intend. It ranges from *robust* to *fragile*. Artifacts used within health care, e.g. automatic infusion pumps need to be extremely robust, not only to ensure that it does not break down at a crucial moment, but also in such a way that it is impossible to mistakenly give it wrong instructions regarding dosage (cf. [27]). Artifacts can be considered fragile if they easily crash, do not work as intended or break during normal use. Note that this means that some artifacts, relying heavily on surprise or challenge, can be seen as fragile in the sense that they may lose their whole point once figured out or experienced. E.g. *Bembo's Zoo*,

where small animations turn letters into animals, is a wonderful, surprising design, but limited. Once explored, it will not be surprising again. It does no longer "work as intended".

Adaptability¹³: This property describes how an artifact adapts to the user's habits and actions. It ranges from *forgetting* to *accommodating* to *expanding*. Forgetting artifacts have no memory of what happened during the last session of use. Artifacts that are public tend to be static, e.g. ticket machines or ATMs – you would not want the ATM to remember your PIN-code in order to suggest it to the next user as a default! Examples of accommodating artifacts are those that remember your last setting and make it default the next time, or that use "common sense". E.g. when opening a new document in *Photoshop* it will default to your latest settings unless you currently have a cut out or copied image in the memory, in which case it defaults to its dimensions. Expanding artifacts reveal more of their functions over use. One example is games where new levels, areas, items or challenges can be unlocked after some time of play. Another example is the *Furby* – a fuzzy, pet-like-toy that (seemingly) learnt more and more words the more the owner played with it and spoke to it.

Openness¹⁴: This property relates to how much an artifact allows the users to change it. It has the following states: *closed*, *customizable*, *changeable* and *codeable*. If closed, nothing can be changed. Shared public devices are often closed, e.g. ticket machines. Customizable allows for the user to change pre-defined things, e.g. a background or sound level, the configuration of tool etc. Changeable allows for users to change content, e.g. as in *Wikipedia* or *Facebook*), whereas codeable means that users can alter the entire artifact if they like, including the change of hardware. Any software-related Open Source-project is per definition codeable.

Properties Related to Complexity

These properties all either contribute, counteract or are effects of an artifact's complexity, i.e. how many different functions it has. It affects interaction in that complex artifacts may be harder to learn, but offer more functions, or, if it's a game, more interesting challenges. How predictable an artifact is, affects the perceived complexity too.

Posture¹⁵: This property, is related to how an interactive artifact "presents" itself, and is based on the type of use it is aimed for. It can be expressed as being *sovereign*, *transient* or a combination thereof. Sovereign artifacts are the center of attention, and are used for longer periods of

⁹ The idea of artifacts being submissive or dominant had been presented and explored by Reeves and Nass [26].

¹⁰ *Level of dependency* is just a renamed version of Löwgren and Stolterman's *Control/Autonomy* [25].

¹¹ *Forgiveness* has been suggested by Martin Rodriguez Rodriguez.

¹² Robustness is a common concept in computer science, and the concept of digital artifacts having fragile forms has been introduced by Landin [14].

¹³ *Adaptability* has been suggested by Niels Reijmer, and is to some extent related to Cooper et al's [4] ideas on considerate products.

¹⁴ *Openness* is a somewhat altered version of Löwgren's *Flexibility* [21], as suggested by Mikael Hjort.

¹⁵ The posture-concept was introduced by Cooper [4].

time, quite often. Typical examples are everyday work tools like *Microsoft Word* or complex games like *World of Warcraft*. As a result sovereign artifacts have many functions, but rely on being learnt, and can thus have information/interaction-dense interfaces (e.g. the “ribbon” toolbar in *Microsoft Word*). Transient artifacts are not used that often, or for short periods of time, in-between or during other activities. As a result, they must be easy to (re)learn and use. Typical examples include simpler music players, or small information-related apps, like the *Weather*-app in the iPhone. An application like *Facebook* lies somewhere in between, since it is used so often that users can be expected both to explore it and remember how it works from time to time, but may not use it for longer periods of time.

Versatility: This property describes how many functions the artifact has. It ranges from *comprehensive* to *limited*. Versatility is often, but not always coupled to posture, since sovereign postures are almost per definition comprehensive whereas transient applications tend to be limited in how many functions they offer.

Predictability¹⁶: This property describes to which extent the user can foresee how the artifact will respond to a certain interaction, or series of interactions. It ranges from *predictable* to *learnable* to *surprising* to *unpredictable*. Predictable artifacts are completely understandable and often quite simple. More complex artifacts often require at least some learning before all their complexities are uncovered. One example is *Microsoft Word*. Many games also contain a certain element of surprise, e.g. easter eggs, or very rare encounters. Surprise can also occur in non-games, e.g. the very popular *Hipstamatic*-app for the iPhone. It simulates an old-fashioned camera with a variety of different lenses, flashes and films, creating effects that make the picture look like it has been taken in the seventies. The effect of using each lense, flash and film can be explored, and thus learned, but the algorithms creating the final result contain enough randomness to be impossible to predict, thus the surprise element. Unpredictable artifacts are just that. Here, the surprise has moved towards a great deal of ambiguity, and these artifacts are often perceived as being strange. Many interactive artworks are unpredictable.

Connectivity¹⁷: This property describes to which extent an artifact is connected to other artifacts, LANs or the internet. There are three states: *networked*, *semi-connected* or *independent*. Networked implies that the artifacts

functions to a great extent rely on it being connected to other artifacts or the internet; any online service is per definition networked. GPS-navigation systems are networked too. A *semi-connected* artifact can be connected to other artifacts, but can function without the connection, e.g. a digital camera which is being connected to a computer every once in a while to transfer images). Or, it may be connected to a few other artifacts, but not to a larger network. If no connection to other artifacts is required, the artifact is independent, e.g. the first generation of the *Furby*-toy.

Difficulty¹⁸: This property describes how hard it is to master an artifact. It ranges from *simple* to *challenging*. Artifacts that aim to be efficient are simple in this respect, e.g. the *iPod* or the *Google* search engine, although the more complex of them sometimes present a challenge in that they are complex and take some time to master fully, e.g. *Photoshop*. Games however, are always designed to contain challenge (cf. [18]) – if we remove the falling pieces and the time-pressure from *Tetris*, allowing the user to just take them and place and replace them whichever way, we have taken the challenge out of it, and the qualities that make it a game, too. Difficulty can be related to physical skills as well; e.g. if the input system is hard to master. SMS-ing using a 10 or 12-button display (as on simpler cell phones) is an example of this.

Properties Related to Change and Time

Interactive products change over time, not only as a result of users’ actions, but also due to their nature of being digital; the digital element can easily be changed. This category of properties thus deal with change – change as movement, as in how time affects a design and change in content or code. They affect interaction either in that they steer what the user can see or do, or in that they help create a certain pace of interaction. In this, they are based on Löwgren’s thoughts on *Rhythm* [24], and several of Lim et al’s time- and movement-related attributes [16].

Evolution¹⁹: This property describes how often an artifact’s functions, appearance or content is changed by external factors, e.g. the manufacturer²⁰. It ranges from *static* to *incremental* to *continuous*. Static artifacts do not change; once they leave the manufacturer they are what they are; this is often the case for physical artifacts like digital cameras. Software applications – and online applications even more – are often subject to incremental evolution via updates or redesigns, *Facebook* being a prime

⁶ *Predictability* is a combination of Löwgren and Stolterman’s use qualities *Anticipation*, *Surprise* and *Transparency* [25], in combination with Lim et al’s *Expectedness* [17] and Landin’s notion of magic interaction form [14].

⁷ *Connectivity* as property was suggested by Lim et al [16], but semi-connectedness has been added to it.

¹⁸ *Difficulty* is a less subjective version of Lundgren’s *Tempting Challenge* [18].

¹⁹ *Evolution* is related to Landin’s ideas on changeable interaction forms [14]. To some extent it is also related to Lim et al’s *State* [16].

²⁰ For changes prompted by users, see *Openness*, for changes built into the software, (e.g. like levels in games), see *Adaptability*.

example, adding new functions and rearranging and redesigning the interface on a regular basis. News sites are an example of continuous evolution.

Movement²¹: This property describes to which extent the artifact, or parts of it are moving. Note that “movement” can be either physical movement, or just changing pixels on a screen. It ranges from *modest* to *dynamic*. Examples of modest movements a progress bar, or the title of a song slowly scrolling by on the display of one’s mp3-player. Examples of artifacts displaying dynamic movement are many games, e.g. *Tetris* or *World of Warcraft*, but also GPS-applications where the map moves along with the user.

Response time²²: This property describes how fast an artifact responds to the user’s actions. It ranges from *fast* to *slow*. Most artifacts (aim to) respond fast, e.g. search engines, but some are deliberately slow in order to create a certain interaction flow, rhythm or feeling.

Temporal aspects²³: This property describes to which extent an artifact is related to time or sequences of events. Its states are *live time*, *real time*, *unbroken*, *sequential* or *none*. Live time is the time we live by, “now”, and examples of artifacts utilizing it are *World of Warcraft* and chats. In real time, a minute is still a minute, but *it is no longer connected to the time in the “real world”*; e.g. a racing game is not coupled to the time of day you play it; you could play in the middle of the night but on the race track the sun is shining brightly anyway. Unbroken Time is when there is an unbroken sequence of events along a time line, but when time can be slowed down, stopped, speeded up, or reversed. Examples include fast-forwarding though a music track on one’s mp3-player, or games where the pace of time can be controlled, like *SimCity*. Other examples are simulations or records of events that can be fast forwarded or slowed down according to interest. Sequential time applies either when parts of a narrative are omitted, but the order remains. This is the case in many games with an underlying narrative, since uninteresting parts are skipped. Another example of sequential time is whenever actions or artifacts have a discrete order based on when they were carried out or created. Examples include an Undo-list, or a collection of photos taken at different times.

Properties Related to Users

These properties describe how the artifact deals with users, user behaviors and relations between users. It affects interaction since the presence of other’s may change how a user interacts.

Company: This property describes whether the user is made conscious of the presence of other users (if any). It ranges from *isolated* to *adjacent* to *accompanied*. An example of being isolated would be an internet bank; even if it has many users, even simultaneous ones, each single user is not aware of the others. Being adjacent is related to users seeing each other’s efforts (e.g. high score lists) or entries (e.g. reviews) whereas being accompanied is related to explicitly interacting with other users, as in for example *Facebook* or *World of Warcraft*.

Locality of users: This property describes how users who are communicating or collaborating are located in relation to each other. It ranges from *co-located* to *distant*. An example of co-located cooperation is playing the game *Rock Band* together. *Facebook* is an example of a tool distant people use to communicate and keep track of each other.

Privacy: This property is related to how much of users’ information and actions are shared with other users of the same artifact. It ranges from *confidential* to *moderate* to *public*. An internet bank is – has to be – confidential, whereas many sites allow for the user himself to decide how much information they wish to share in their profile. Another aspect of moderate is the fact that a person can be observed using a physical device, e.g. a mp3-player, but the observers may not know which music the person listens to, or someone can be seen withdrawing cash from an ATM, but not how much, or what the person’s PIN code is. Most social media artifacts strive to be as public as possible.

Behavior analysis: This property describes to which extent a users’ actions are recorded, remembered and or analyzed. It ranges from *inactive* to *active* to *exploiting*, where inactive artifacts are ignorant of who uses them how and when. Examples include music players and digital cameras. In order to be accommodating, e.g. suggest music, a certain amount of active behavior analysis is required. Another example of active analysis is when the sum of user actions (users may be anonymous or not) are used to draw conclusions on the use of the artifact, e.g. to create top lists. An example of exploiting is when the artifact explicitly keeps track of an individual’s actions and uses it for surveillance purposes or business purposes. Note that this property is relevant only if users realize that their behavior is being analyzed, since it may then affect interaction.

DISCUSSION

There are undoubtedly many issues related to this collection of properties. For instance, some properties seem to be missing, e.g. aspects of navigation is “hidden” under feedback (as an example of pre-action feedback). Other properties seem to cover a lot of things, or can differ within the same artifact (e.g. the *Information Order* on a Wikipedia page is ordered, but on Wikipedia as a whole, it is scattered/hyperlinked). And, undoubtedly, some readers will miss properties they think should be added, or find the presence of others questionable.

¹ *Movement* is a combination of Lim et al’s *Movement* and *State* [16]. Here, the scale is changed somewhat.

² *Response Time* is an altered version of Lim et al’s *Speed* [16], omitting user’s responses.

³ *Temporal aspects* is based on the first four Temporal themes as described by Lundgren & Hultberg.

Property	Definition	Range	Related to
Adaptability	How an interface adapts to the user's habits and actions.	<i>Forgetting–accommodating–expanding</i>	Behavior
Approach	Which interactive stance the artifact takes towards the user.	<i>Submissive–suggestive– dominant</i>	Behavior
Behavior analysis	To which extent a user's actions are recorded, remembered and or analyzed.	<i>Inactive –active–exploiting</i>	Users
Clarity	How clear an artifact's output or appearance is.	<i>Distinct–ambiguous</i>	Expression
Company	Whether the user is made conscious of the presence of other users.	<i>Isolated–adjacent– accompanied</i>	Users
Connectivity	To which extent an artifact is connected to other artifacts.	<i>Networked, semi-connected or independent</i>	Complexity
Difficulty	How hard it is to master an artifact.	<i>Simple–challenging</i>	Complexity
Directness	How “hands on” interaction is.	<i>Real-world manipulation–direct manipulation–indirect manipulation</i>	Interaction
Evolution	How often an artifact's functions, appearance or content is changed by external factors, e.g. the manufacturer.	<i>Static–incremental–continuous</i>	Change and Time
Feedback	The different aspects of feedback.	<i>Rich –poor. Modal, modeless, post-action and/or pre-action</i>	Expression
Forgiveness	How forgiving an artifact is towards the user's mistakes.	<i>Forgiving–unforgiving</i>	Behavior
Freedom of interaction	In how many different ways one can attain a certain outcome.	<i>Forced –free</i>	Interaction
Information order	How information is ordered.	<i>Linear–scattered, hyperlinked, or multimodal</i>	Expression
Interaction flow	The fluency of interaction.	<i>Continuous–discrete</i>	Interaction
Input modalities	With which devices input can be made.	Input devices	Interaction
Level of dependency	How much interaction the artifact requires.	<i>Autonomic–dependent</i>	Behavior
Locality of users	How users who are communicating or collaborating are located in relation to each other.	<i>Co-located to distant</i>	Users
Movement	To which extent the artifact, or parts of it (which may well be digital), are moving.	<i>Modest–dynamic</i>	Change and Time
Openness	How much an artifact allows the users to change it.	<i>Closed, customizable, changeable or codeable.</i>	Complexity
Output modalities	With which devices output is made, as well as their modalities.	<i>Devices. Vision modality, auditory modality, tactile modality etc. Singlemodal or multimodal</i>	
Posture	How an interactive artifact “presents” itself, based on the type of use it is aimed for.	<i>Sovereign, transient or a combination thereof</i>	Expression
Precision	The level of precision one has in input.	<i>Proximate to precise</i>	Interaction
Predictability	To which extent the user can foresee how the artifact will respond to a certain interaction, or series of interactions.	<i>Predictable–learnable–surprising–unpredictable</i>	Complexity
Presentation	The richness of information that is being presented.	<i>Scarce–detailed</i>	Expression
Privacy	How much of users' information and actions are shared with other users of the same artifact.	<i>Confidential–moderate–public</i>	Users
Response time	How fast an artifact responds to the user's actions.	<i>Fast–slow</i>	Change and Time
Robustness	The ability to cope with unintended use, misuse or abuse.	<i>Robust–fragile</i>	Behavior
Temporal aspects	To which extent an artifact is related to time or sequences of events.	<i>Live time, real time, unbroken, sequential or none</i>	Change and Time
Tasking	Whether the artifact allows for concurrent tasks.	<i>Multitasking or singletasking</i>	Interaction
Versatility	How many functions the artifact has.	<i>Comprehensive–limited</i>	Complexity

Table 1: Interaction-related properties, listed alphabetically

All of these issues are valid. However, the ambition has been to keep the collection comparably small, still being able to review and learn. As a result it is not – cannot be – finished or finite; any designer may redesign it to fit their own need. Since the ambition is to create something that will be used, a certain amount of customization is *welcomed*.

Another issue is the categories: they work well for most properties, but are problematic for some, e.g. placing *Movement* in Change and Time instead of in Expressions, or placing *Robustness* in Behavior instead of in Interaction. In all the dubious cases, the judgment was to place the ambiguous property in that category and context where it seemed to belong the best. E.g. the similar properties *Adaptability* and *Evolution* were placed in Behavior and Change and Time respectively, this since the changes regulated in *Adaptability* are related to adapting to one certain user (i.e. displaying a certain behavior towards that user) as opposed to the more neutral *Evolution* which is carried out regardless of the actions of individual users. But, given that there are thirty different properties, it is probably impossible to find a category framework that fits all of them. Overall, the point in dividing the properties into categories in the first place was to make them easier to overlook, since they now come in “chunks” of 4–6 properties. The categories in themselves are not as important as the properties.

Another issue is how some properties in different categories are strongly interrelated, e.g. *Locality of users* postulates that users are aware of each other (implying *Company*) and that if they are remote, there is a connection (implying *Connectivity*). Similarly *Freedom of Interaction*, i.e. if there are many ways to do the same thing, is strongly tied to *Versatility*. A more thorough analysis would probably result in a complex web of interrelations between the properties – very interesting, and future work indeed, but not within the scope of this first step of describing the properties.

It may seem strange to split up such complex things as interactive artifacts as a list of properties, or as put by Löwgren and Stolterman: “The *overall character* of a digital artifact cannot be described by simply adding up a number of particular qualities” [25]. This is true, and this is also why the descriptions at this point do not give any detailed suggestions of exactly how the different attributes and their states affect interaction (although some most are common-sense); depending on combination of property states the interaction may change. The taxonomy is by no means a crystal ball where future use can be envisioned with absolute clarity. It can only give indications, and feed for thought. What it *can* do though, is give counter-indications: If an artifact’s *Difficulty* lacks any challenge whatsoever, it is most likely unsuitable as a game. Or, if the *Predictability* of an artifact is judged as being unpredictable, it will probably not be very efficient to use.

Despite these issues, there are several uses of the collection. Just like pattern languages (cf. [2], [3], [9], [29]), it can be used as a tool for analysis and comparison – albeit not for interactive devices as a whole, but only for the interaction-related aspects. As analysis tool, it serves as a way to deconstruct a design, as well as a way to find out why an artifact does not work as intended. Additionally, it can help when comparing two similar artifacts, analyzing why they differ. Secondly, it can be used as a kind of checklist during development; making conscious decision regarding each property instead of just “letting it happen” will hopefully result in better designs.

Most interesting however, is that it can be used as a tool for re-design. When teaching, I have had several classes of design students analyze an artifact in terms of Löwgren and Stolterman’s use qualities [25] and then deliberately change them to see what happens, or transfer Lim et al’s gestalt attributes [16] between artifacts (see [19]). In many cases this has resulted in surprising insights and new designs. This shows how listing and then toying with properties can result in improvements or new ideas, e.g. changing Word’s *Connectivity* to networked and *Company* to accompanied would result in a Google-Docs-like application. Moreover, the most important benefit of the collection is that it, as the aim was, extends the interaction designer’s vocabulary; providing a shared set of terms that we can use whenever discussing or describing interaction.

CONCLUSION

This collection of thirty interaction-related properties of interactive artifacts may still need to be improved in terms of which properties should belong, and how they should be categorized, but nevertheless, the collection of properties describe – on an overarching level – how an artifact interacts, and how it lets users interact with it. As such, it can serve as: a valuable tool when analyzing, discussing and describing the means of interaction with interactive artifacts; as a checklist during design; or as a tool for redesign. Future work includes to study the interrelation of the properties, as well as to more thoroughly describe how they affect interaction.

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Furby, Hasbro, <http://www.mimitchi.com/html/furby.htm>
Google, Google Inc, www.google.com
Hipstamatic, Synthetic Corp. <http://www.hipstamatic.com/>
iWeather, NPC NV, <http://www.apple.com/webapps/weather/iweather.html>
Last.fm, Lastfm Ltd., www.last.fm
Microsoft Word, Microsoft, <http://office.microsoft.com/en-us/word/>
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Interactive Digital Art

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ABSTRACT

In this paper, we present DNArt in general, our work in DNArt's lab including a detailed presentation of the first artwork that has come out of our lab in September 2011, entitled "ENCOUNTERS #3", and the use of DNArt for digital art conservation. Research into the use of DNArt for digital art conservation is currently conducted by the Netherlands Institute for Media art (Nederlands Instituut voor Mediakunst, NIMk). The paper describes this research and presents preliminary results. At the end, it will offer the reader the possibility to participate in DNArt's development.

Keywords

DNArt, living system, new media art concept, digital art conservation

INTRODUCTION

DNArt is defined as a work of art that by concept will grow and change in time. Where traditionally a work of art is an object, DNArt will behave much more as a subject that interacts with and learns from its surroundings.

Characteristics of DNArt

DNArt presents a model for computer-based works of art. DNArt's mission is the creation of art that:

- is capable to maintain and develop itself;
- can easily interconnect with people, social networks, and similar works of art across the globe;
- can learn from and by its interactions;
- will have relations with people, institutions, and businesses;
- behaves like a living system;
- will become legally independent (as a foundation) and will be able to manage its own resources.

In short, art that will behave much more as a subject rather than an object.

Development of DNArt

DNArt was initiated by Bill Spinhoven van Oosten and in order to let DNArt reach out more easily to potential co-developers, a cooperation with the Pervasive Systems research group at the University of Twente was initiated in November 2010. As a result of this cooperation DNArt uses the Smart eXperience (SmartXp) research lab¹ of the Faculty of Electrical Engineering, Mathematics and Computer Science at the University. SmartXp is a living lab, which aims to provide an interactive environment for researchers, user groups, artists, and social scientists to work together on the creation and evaluation of the next generation of ubiquitous systems and their impacts. Some parts of the development of DNArt have been integrated as projects in the curriculum of the University in the form of student assignments. Within these assignments students will look at, for example, creation of real-time 3D reconstruction of activities captured by Kinect motion sensing input devices as well as creation of interactive digital art.

In the following, we present one of our interactive digital art works created using DNArt.

ENCOUNTERS #3

The digital art work entitled "Encounters #3" is the third work in the "Encounter" series, in which the viewers can see themselves on a screen on the wall in the exhibition space. The screen shows the footage of a video camera that is hanging against the ceiling looking down at the exhibition space. The live image is delayed by five seconds and virtual visitors are added to the image. As a result the viewers can see themselves together with virtual visitors within the exhibition space. The key idea from the visitors' view is that by entering the space, one starts interacting with these virtual visitors.

Technique

The virtual visitors are selected from a list of prerecorded movies. The selection is done in a way that assures that the spots at which the virtual visitors appear are not at the same time occupied by a live visitor. The five-second delay gives the system some pre-knowledge about the behaviour and position of the visitors. The list of movies to choose from is categorized according to themes giving the

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¹ <http://smartxp.ewi.utwente.nl>

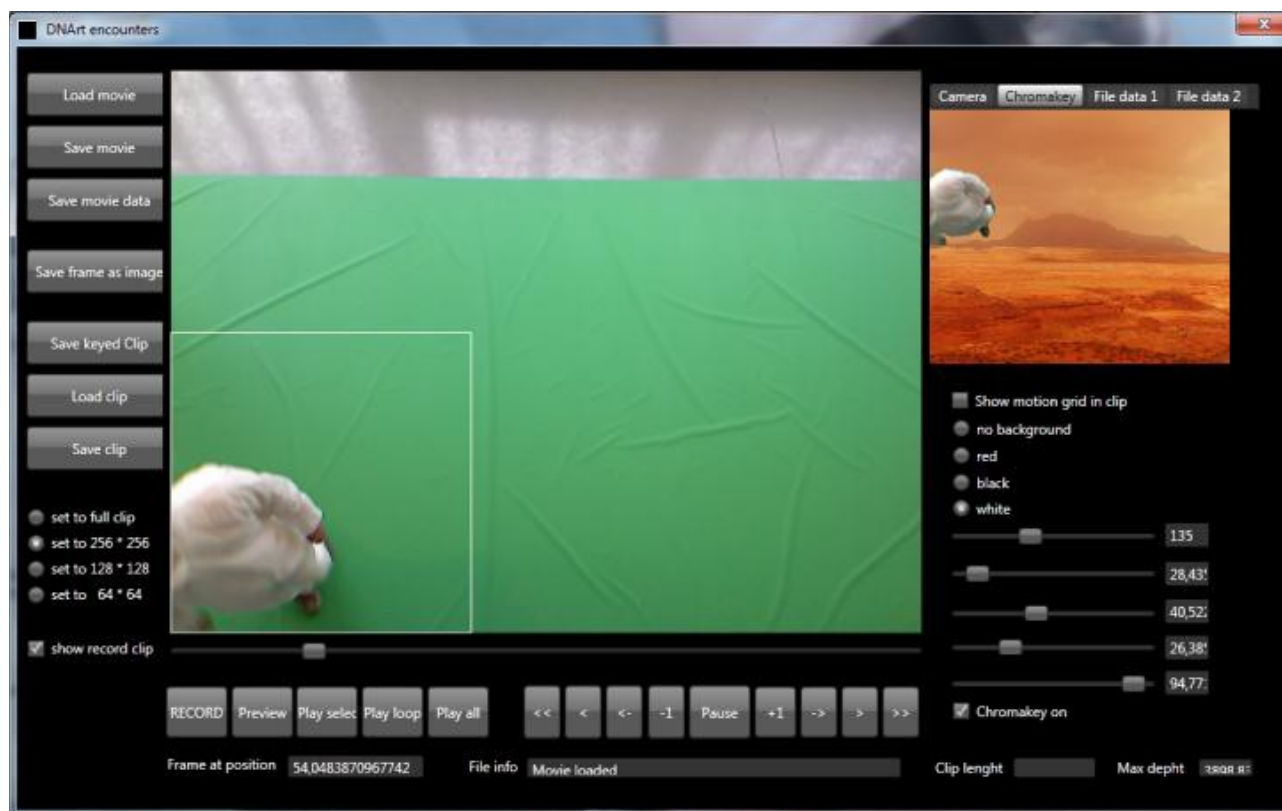


Figure 1. Screenshot of “Encounters #3” interface software

installation the option to behave differently on different occasions or at different events. For the creation of the movies we asked for public participation and all of the virtual visitors were created with the assistance of people present at the exhibition space.

Software

In order to make the process of the creation of the movies as easy as possible, a special program was created, see Figures 1 and 2. The ease of the program gave us the possibility to focus on the interaction with the actors.

The length of each recorded movie is only 10 seconds and this practically removes any hurdle to participate as an actor for the movies.

The fact that the final result can be viewed immediately before the next recording gives the whole process of recording a feeling of interactivity. Feedback can be used directly for the next recording. The program also generates a masked movie clip with data about the position of the virtual visitor. The clips contain additional data about their length, resolution and some other items, but one property we would like to mention in particular has to do with the ability of clips to loop at some point. This loop (which can be as short as a single frame) is typically used to make clips longer.

The following example scenario illustrates this process.



Figure 2. Extra menus in “Encounters #3” interface software

A virtual visitor enters the room and stands still.

The virtual visitor's movie enters a loop of one single frame effectively freezing the movie and making the virtual visitor stand still.

The virtual visitor maintains this position until some real visitor comes too close (or the maximum allowed duration of the loop has passed).

The virtual visitor leaves the room.

The real person moves to the place where the virtual visitor was before.

Because of an introduced delay of five seconds, we know where our real visitors are going to be in five seconds, so it is relatively easy to check if a visitor will get too close.

Presentation Framework

The prerecorded movies combined with the live camera input are used by a second program whose output is shown on the screen in the exhibition space, see Figure 3. They are used as textures on the floors of a three-dimensional (3D) model. The model itself can be created by any 3D modelling program as long as it is saved as a platform-independent 3D Data Interchange Technology (FBX) object [2]. For our program we have chosen Microsoft's XNA 4.0 [12] as the 3D framework. The only reason for this choice was the fact that our lead programmer had some experience with this framework.

The 3D framework also allows us to use the camera as a tool for expressions: just like in a regular movie we can move the camera to emphasize certain parts of the image. Furthermore, by using a 3D framework we can give visitors from separate geographical locations the illusion of being within the same building or object. This illusion can be created by using the combined movies as textures for floors in a 3D model.

The program has no regular graphical user control because the output of the program is shown on the presentation screen, thus that would be impractical. Instead of a graphical user interface (GUI) the program can be controlled through Open Sound Control (OSC) [13]; this allows us to view and set debug parameters and variables at a remote location. This interface can also be used by other remote programs to interact with the presentation.

Living System

Since "Encounters #3" is a living work of art, it wants to learn and explore its wealth of possibilities. It does so by actively seeking participation from the audience and all other people and institutions it interacts with. This participation can be on a technical level, like for instance helping to make "Encounters #3" detect the visitors and their actions better, or on an more artistic level, like exploring the cinematographical possibilities of this new world.

The "Encounters" series explores the concept of interaction with the viewer and as such forms a phase in a development towards something like interactive cinema.

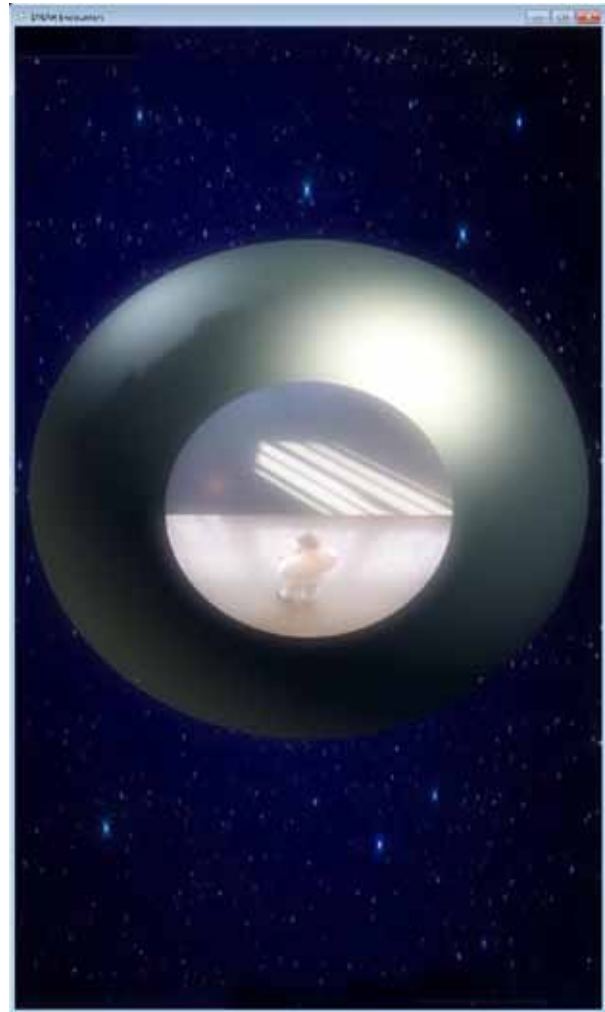


Figure 3. Screenshot of "Encounters #3"

Figure 4 shows the first work in this series, which is titled "Encounters #3". The current work, "Encounters #3" can connect two geographical separated locations in such a way that visitors are able to interact with each other.

DNART'S DNA: ENABLING TECHNOLOGIES

DNArt's software consists of virtual machines that can communicate with sensors and actuators as well as with each other by standardized methods. These methods include Open Sound Control [13] and IEEE 1722.1 [9] and have been chosen for their use of time stamps. This way, actions can be synchronized and sensor data can be integrated more easily.

Sensor and Actuator Networks

Use of sensor and actuator networks is a well-known concept in the field of digital media art, in which creation of dynamic installations is the main focus. The concept behind these installations is rooted in creating a dynamic experience for the visitors by reacting to their presence and/or interactions through sound and gesture. While sensors and actuators have been used in the process of creating digital media art, use of sensor and actuator



Figure 4. “Encounters #1”

networks instead of individual sensors and actuators has received little or no attention. To this end, sensor and actuator networks can offer fine-grained spatial and temporal situation awareness on art works which enables in-situ monitoring of environmental conditions around the art installation and analysis of their impacts on its presentation and performance.

The situation awareness offered by the sensor and actuator networks not only includes monitoring and analysis of the art installation itself but also offers a new possibility to observe the visitors and their interaction with the installation in a privacy-aware manner. To this end, the visitors and not the art work are object of observation. In contrary to the common concept of filming the visitors, sensor and actuator networks can offer an unobtrusive manner of online detection of visitors’ activities through online feature extraction and pattern recognition in which activities rather than each individual form the focal points.

Open Sound Control

The method we currently use most for communication between virtual machines, sensors, and actuators, is Open Sound Control (OSC). This is an open, transport-independent, message-based protocol developed for communication among computers and other multimedia devices [13]. OSC uses a network port for its communication. We combine the use of OSC with a zero configuration service [16] to publish information like the port address to other devices and services.

Zero configuration networking allows devices such as computers and sensors to connect to a network automatically without the need to configure each computer’s network settings manually. There are several ways to implement zero configuration and we have used Apple’s Bonjour.

Audio/Video Bridging

Although OSC is very useful for most of our needs it lacks standardization for dealing with queries. This has led to many ad hoc solutions, one for each out of many implementations. Our approach is to follow and combine the methods proposed by Kofinoff [11] and the methods used by Jamoma² [14] as closely as possible. Although AVDECC was chosen over AVBC as the way to go for Audio/Video Bridging (AVB), many of the proposed implementations, like the OSC \leftrightarrow JSON conversion, are suitable for DNArt. Another problem with OSC is the fact that it does not lend itself well for streaming large amounts of data. This is why we intend to use the following IEEE 802.1 Audio/Video Bridging protocols and standards in the near future:

IEEE 802.1 AS — Timing and Synchronization for Time-Sensitive Applications in Bridged Local Area Networks (LANs), a precision time synchronization protocol [5];

² <http://jamoma.org/>

- IEEE 802.1 BA — Audio/Video Bridging (AVB) Systems [6];
- IEEE 802.1 Qat — Stream Reservation Protocol (SRP); an end-to-end bandwidth reservation protocol within a bridged LAN [7]; and
- IEEE 802.1 Qav — Forwarding and Queuing for Time-Sensitive Streams: A/V traffic scheduling enhancements for mainstream Ethernet and other network switches [8].

Utilizing AVB, the transmission of audio and video streams can be synchronized within a microsecond, with low delay, and minimal data loss caused by network congestion. The range of delay and amount of lost data depends on the particular network technologies (e.g., Ethernet, wireless) on the stream path. For example, in the case of a full-duplex switched 100 Mb/s Ethernet network that implements AVB, any two endpoints that establish a stream reservation have less than 2 milliseconds (ms) packet delivery delay, less than 1 microsecond (μ s) synchronization error, zero long-term wander, low jitter and zero data loss due to congestion.

There are also two draft standards that rely on IEEE 802.1 AVB to provide professional quality Audio/Video:

- IEEE 1722 — Layer 2 Transport Protocol for Time-Sensitive Streams, which allows easier porting of applications, currently IEEE 1394 (FireWire®) to AVB [9]; and
- IEEE 1733 — which extends RTCP for RTP streaming over AVB-supported networks [10].

There are several methods proposed within the IEEE 1722.1 standard as the way in which an Ethernet AVB controller could discover the capabilities of devices on an Ethernet AVB network:

- ZeroConf (Apple's Bonjour);
- IEEE 1722.1 AVDECC;
- IEEE 1722.1 AVBWEB; and
- IEEE 1722.1 microsupport, a minimal protocol for simple and fast connection management and control of AVB devices.

The Use of Timetags and Timing Mechanisms in DNArt

Timing is a precarious topic in relation to virtual computers [15]. However, we need precise timing when we combine data from several sensors or creating simultaneous events in different nodes on a network. Because of this, special care has been given, with the choice of our communication protocols, to the standard implementation of so-called timetags. Both AVBDECC and OSC have the ability to add information about timing. They also contain methods to synchronize clocks (for OSC there are several proposals how to do this). AVB was specially developed to solve the timing and synchronization issues inherent in AV over Ethernet. So it will be no surprise that one of its most important tasks is to provide precise timing.

Generally one AVB device supplies a clock value and all other devices in the network follow the clock. This method is specified in a separate IEEE standard, 802.1AS [5]. The device supplying the clock is called the Grand Master Clock and can be automatically chosen. This facilitates auto configuration. If needed the clocking device can be synchronized to other system clocks. Timetags can also be used to ensure commands will be executed simultaneously at some time in the future (by giving them a future timetag). This concept can also be used for bundling a sequence of commands as a method to significantly reduce network traffic in comparison to sending them one by one. To solve the problem of varying speed with regard to program execution on different virtual computers, the concept of a master clock was applied here as well. Often the refresh rate of a sensor (i.e., camera) was used when no other master clock was connected to the system.

COMPUTER ART CONSERVATION

DNArt is a living work of art; its structure was specifically chosen to be long lasting. These robust features of DNArt's DNA seems to provide an ideal model for the conservation of media art.



Figure 5. "I/Eye" (1993)

DNArt will also provide additional tools for conservators to gather information about user interaction and monitor the functionality of the work.

Virtualization as a Preservation Strategy for Digital Art

To enable easy and meaningful interaction with digital art works on the one hand, and correct conservation of the digital arts on the other hand, one needs to find proper methods and tools. To this end, a fundamental question to be answered is whether virtualization is an adequate method to enable an audience to experience computer-based installations in times when the hardware and software formats used in the artwork have become obsolete and whether it offers an option for their preservation for the future.

Case Study

In order to explore this we conducted an empirical study into the installation “I/Eye” (1993) by Bill Spinhoven van Oosten using the structure DNArt. The results of this study were positive. During the symposium –To transfer or to transform (on the 24th of February 2011 at NIMk in Amsterdam) an emulated and virtualized clone of “I/Eye” was presented side-by-side with the original “I/Eye”. Although the original (see Figure 5) was running on a computer from 1993 that used a completely different processor architecture, no noticeable difference could be detected by a professional audience.

The website <http://conservation.DNArt.me> provides some preliminary documentation on this case study conducted for the NIMk. The proceedings of this research are extensively discussed by Hölling in [3] and [4].

CONCLUSIONS

The use of virtual computers as used by DNArt has proven to be very useful for media art conservation in general.

The start of our first implementation of DNArt has generated a lot of support, publicity and interest into DNArt.

We actively seek further cooperation with all interested parties. We have ported our software to Github Social Coding³, though we have to keep the software in a closed repository for now. This is due to uncertainty about the licenses of software components. Nevertheless, anyone interested in co-developing parts of DNArt is very welcome to contact us.

Lessons Learned

We encountered a number of limitations in the use of the Kinect; most were due to the fact that the version of the Software Developer’s Kit (SDK) we are using is still a beta version. Through discussions on forums we found out that most issues we encountered will be resolved before the official release of the SDK. These issues are: no gain and brightness control for the colour camera, limited-depth data (the maximum depth value is 4 meter) and lack of support for virtual computers.

ACKNOWLEDGMENTS

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Kinect is a registered trademark of Microsoft Corporation.

Bonjour is a registered trademark of Apple Inc.

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Embedding Designed Deformation: Towards the Computational Design of Graded Material Components.

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ABSTRACT

Recognising that the process of making materials affords opportunities not available when using existing natural or off-the-shelf materials, the focus of this paper is upon abstraction strategies by which the mechanical properties of composite materials might be engaged within digital architectural models. A proof of concept is developed around the process of designing, making and simulating a graded thermoplastic mono-composite sheet, which exhibits controlled deformation under loading.

Keywords

Digital design, composite materials, graded materials, material properties

INTRODUCTION

Today, material performance is regarded as one of the richest sources of innovation [5,21]. This emerges from the knowledge that far from being inanimate ‘stuff’, materials respond to forces in complex ways [7]. The ability to actively and productively use these behaviours within design is linked to advances in computation, fabrication and material science, and opens up new material, tectonic and sustainable possibilities for architecture [6, 19].

Accordingly, architecture is shifting to practices by which the computational generation of form is directly driven and informed by material characteristics. At the same time, there is a tendency towards the individual composition of material. Recognising that the process of making materials affords opportunities not available when using existing natural or off-the-shelf materials, this paper looks to the concept of composites as a basis from which to develop both a designed material prototype and a simulation strategy that incorporates material properties within digital models.

The focus of the paper is upon the abstraction strategies by which the material properties of composite materials might be better engaged within digital architectural models. Specifically, the paper considers one aspect of the conceptual framework that underlies composite materials, the rules of mixtures, and the distinctions in thinking by which this might be implemented within an architectural 3D model. A proof of concept is presented that integrates relationships between the constituent properties, their configuration within the material, and the macroscopic properties of a structure under load.

The proof of concept is developed around the process of making and simulating a graded thermoplastic mono-composite sheet. The mono-composite sheet is varied at the meso-scale, with the result of graded stiffness. Via this approach the bending behaviour of the sheet can be controlled. A digital model that pairs a parametric model and finite element analysis has been developed that accurately simulates this bending behaviour and outputs material fabrication information. The proof of concept is confined to the design and simulation of a sheet material.

COMPOSITES

Composites, which represent some of the oldest building materials as well as the most modern, combine multiple materials to create a new material with properties beyond that of its components [6]. As materials that are capable of being designed for specific contexts and performances, they rest on two basic ideas. The first of these is that, if a material does not exist, it can instead be made through the combination of two or more component materials [2]. Secondly, that the properties of this new material, for example the mechanical relationship between form and force that it exhibits, is dependent upon the organization of these components within the material. Following this, if a material’s properties depend on its internal structure, and that structure can be designed, it then becomes possible to control load transfer and therefore mechanical deformation

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in bending, flexure, tension and shear so that the material meets specific purposes and exhibits controlled behaviours. These might be to counteract load in a particularly efficient way, or to change shape in an abnormal way under loading so as to perform a certain function [4]. As designed synthetic materials, composites form the basis for an expanded architectural practice, but their use implies the navigation of an unknown space, outside the properties of more familiar materials.

In their modern conception, composites are most typically comprised of fibres that reinforce a matrix [22]. They are at the leading edge of materials technology with applications such as aircraft and transportable structures on account of their high strength and low weight, properties that emerge from the orientation of the fibre. However, it is the matrix phase which most affects the cost, processing and level of specificity that a composite is able to achieve. For this reason, thermoplastic polymers are increasingly favoured over more traditional thermoset plastics since they allow for significantly easier working methods and far greater precision. Underlying this shift are many advantages: thermoplasts can be recycled many times without loss of properties, are cheaper than thermoset resins, and require much less energy to process. By virtue of their easier working methods and increased precision, thermoplastics such as polyethylene (PE) and polypropylene (PP) significantly extend the capacity of composites for the specific, and afford the opportunity to rethink a relationship that, in its limited modern focus upon stiffness and lightness, production methodology and price, has perhaps tended towards the generic.

Thermoplastics make it more possible to vary a property within a material, creating what are known as graded materials. Such materials can be either structurally or functionally graded (FGMs), and are commonly found in nature, in bio-tissues of animals, such as bones and teeth, and plants [14]. While a homogenous or isotropic material has the same properties in every direction, and most composites are anisotropic, with different properties in different directions, graded materials are characterized by non-uniform distributions of the component materials, thus varying in property and creating multiple functions within the material [11]. Because of this, they allow the full integration of material, contextual and structural considerations in the design of material components [24]. As distinct from fibre reinforced composites, where the orientation and distribution of the fibre determines the properties, in graded materials it is often control over the volumes of the component materials that becomes the means of optimising the material for specific applications.

The move to thermoplastics and graded composites expands the scope of application and spatial possibility for composites, and the design parameters that an architect can draw into their design process. However designing graded

composite materials is a very different task to specifying traditional materials.

FROM SELECTION TO DESIGN

Historically, architects were limited to selecting natural materials based on their understanding of their extrinsic properties and performance [1]. With the industrial revolution, material advances such as iron, steel and reinforced concrete altered the course of architecture [6], impacting upon design methodologies, general conceptions of form, and modes of production [19]. The new engineered materials allowed for standardized properties and for specialization, and replaced a practical experience of materiality that was intuitive and empirical.

Exemplified in modernist tectonic thinking, specification and specialization allowed buildings to be broken down into material specific systems, which could again be differentiated into, for example, nodes that connect and beams that carry, and then again into beams that are sized differently according to their loading. In this manner, a building could be assembled from parts that reduce in scale at each level, with each level distinct from the orders above and below it, and structurally supporting those levels that come afterwards [3]. Here, materialisation and the control of properties becomes largely about minimizing behavioural change and neutralising its effects [10].

In one view, designed materials with graded properties could be considered as continuing this tradition of differentiation and specialization, but at a new scale where the opportunity is to work at the level of the material itself. Addington suggests such a possibility in the context of smart materials: *“smart materials are often considered to be a logical extension of the trajectory in materials development toward more selective and specialized performance”* [1]. But designing material properties from the bottom up, rather than shaping them from the top down, suggests changing possibilities for the association of parts and wholes. One example can be found in Beesley and Hanna’s discussion of Peter Testa’s Carbon Tower, in which they argue that the ability for fibre reinforced composites to incorporate what would otherwise be joints and abrupt changes in material implies a break from the tradition of reductionism, and an almost complete abandonment of the principles of hierarchies in building systems [3]. A second example, which pursues material specificity while maintaining the idea of parts, can be found in the thinking of Viollet-le-Duc, who extended his notion that it would be *“more natural to give these materials the forms suitable to them, and to arrange the architectural features accordingly”* into material itself: *“We ought to be able to analyse a building, as we take a puzzle to pieces, so that the place and function of each of the parts cannot be mistaken... each piece of dressed stone is an indispensable member, complete in itself, - a kind of*

organ which, subjected to analysis, finds its exact place and function in the whole” [17].

REPRESENTATION

While graded composites hold much potential for design, they also introduce significant added complexity to the design process. Materials that are designed for a particular performance require representations that link that performance to the design process. Similarly, materials that vary continuously in their composition cannot be accurately represented at just the bulk level. As Delanda has argued, it is *“precisely those abilities to deal with complex, continuously variable behaviour that are now needed to design structures with the new composites” [7].*

Most tools for architectural representation do not support the active description of materiality. Instead, materials are conceived of as homogenous and static bulk elements and, unable to engage in deep entanglements of structure, form and loading, architectural representation has instead privileged the description of the surface [1] and regulated materiality to empty spaces between the lines [18]. But architecture is now increasing its ability to engage material properties within the digital design process and an accompanying adjustment of the tools, methods, models, and media employed by designers to develop appropriate design strategies is underway; these digital tools are better able to describe the complex and novel underlying organisational structures that are required. The use of analytic, parametric and constraint based software as well as scripting and physics-based calculative tools forms the basis of this exploration [13, 25, 26].

While 3D modeling tools have allowed architects new approaches, and in particular extended the ability to incorporate properties linked to fabrication, for the most part they remain geometrically focused, that is to say concerned with the geometrical attributes of components and the topological and compositional relationships that associate them. This approach is well suited to integrating extrinsic material properties, such as bulk dimensions, volume and centre of gravity, but lacks the capacity to capture those material properties not easily described through explicit geometry. In the case of a component for example, mechanical properties can be empirically tested, measured and then encoded in abstract relationships within a parametric or scripted model, so that they are filtered through bulk geometric characteristics because constant material properties are assumed. Such an approach works well if the deployment of the component matches the empirical testing exactly, but these approaches cannot be applied directly to the design of composites with graded properties because it is the underlying materiality that is being varied, below the level of the component.

Approaches to integrating composites and graded materials remain a challenge, because they require early stage modeling tools and strategies that incorporate varying

organisations and combinations of properties. This requires a different set of conceptualisations. How then can we think about designing below the level of the component, using a digital model to make relationships between the constituent properties, their configuration within the material, and the macroscopic properties of the structure, keeping in mind that the purpose is to make models *for* incorporating the design of material as distinct from models *of* material? [16]

CONSIDERING MATERIAL AS A SET OF CONDITIONS

As materials that are designed specifically for deployment, composites do not pre-exist that deployment, and are therefore very different to natural materials. Not being found objects, they can be more productively considered as a set of conditions, since they describe a particular state or a set of circumstances and are also a proposition on which another proposition (the deployment) depends.

The first of these conditions relates to scale, and the second to configuration. All materials can be thought of as nested structures, whereby the properties emerge from interactions across scales. All materials combine *“macrocosm and microcosm [which] consist of innumerable material objects. Each material object has a form. Each material object is capable of supporting and transmitting forces” [20].* While these material objects exist across different scales, they establish interdependent relationships between each other, exhibiting what CS Smith variously described as the *“interwoven importance of atoms and aggregates”* and *“the deep entanglement of macro and micro” [23].* Composites allow us to engage with this diagram directly, by understanding that the properties of the whole system depends on the properties of the constituent materials, their concentrations and / or orientations, and the response of the material to conditions of load and restraint. These parameters can be understood through reference to three interconnected scales - the micro, meso and macro - and through reference to the concept of the rules of mixtures, simple equations used within material science to determine a property of a composite in terms of the properties, quantity and arrangement of its constituents.

The micro scale – small compared to that of the components— encompasses interactions and arrangements that occur at a molecular scale, and is typically measured in nanometers. Many of the properties of matter are determined by the properties of molecules and atoms - in the case of polymers for example, the length and branching of molecular chains determines the structural properties of the plastic as a whole. In the architectural context, this is not a scale of design but rather of selection based on desired properties [2].

The meso scale exists between the micro and macro scales, at one scale below that of the component, and can be measured in millimeters. At this scale, material elements are organized either via inherent properties or by design

into physical structures that are much larger than the micro scale, but much smaller than the macro scale of the material. In many different kinds of materials and systems, the properties and interactions at this scale determine the overall properties of the material. Examples include cracks and imperfections in metals [2] and turbulence.

The macro scale – large compared to that of the components— is the bulk scale of the material element. It has a shape, is restrained and accepts loads, and exhibits resultant properties, in this case a mechanical response to force.

At the meso-scale, configuration becomes important. The component materials within a composite may be configured in different ways, for example as particulates, long or short fibres within a matrix, or as sandwiches or laminates. The chosen configuration is often driven by the length scales of the constituent materials, the means of fabrication, the loading that is expected, the scale of the bulk object etc. In a graded material, a particular configuration will be varied across the material.

There are approaches to the representation of graded materials that geometrically model these configurations, however it is recognized that major disadvantages include the requirement for a lot of memory, and being too complex [10]. Materials science provides a different approach, based on simple equations to capture compositional distribution at this scale, called ‘rules of mixtures’ [2]. These equations are used to approximately calculate a property of the composite with regard to properties, volume fraction and arrangement of the constituent materials. They rely on the assumptions that at the macroscale, a composite behaves like a homogenous solid with its own set of thermo-mechanical properties, and that the mechanical behaviour of a composite results from load sharing between the two constituent materials. That is to say that a certain proportion of load will be carried by one component material and a certain amount by the other. The proportion of load carried by each can be determined by volume-averaging the load within a unit or element of material [12]. If the material is isotropic or anisotropic the unit to which the rules of mixtures is applied is that of the object, but if the material is graded the unit needs to be at the scale of a unit smaller than the object.

There are many rules of mixtures, each describing specific material arrangements. For example, to calculate the bounds between which the e -value of a non fibrous composite should lie, two rules of mixtures are used: the Voight (upper) and Reuss (lower) bounds. Each is a simplifying assumption that needs to be calibrated for particular cases, however the benefit of this numeric approach is that it provides a way of engaging the meso scale, and thereby designing the relationship between load and resultant behaviour, while avoiding the modeling of individual geometries.

The following section describes, through the making of a graded mono-composite sheet, how these distinctions in thinking that can be made within an architectural digital model so that it is able to involve another level of material parameters for the purpose of simulating a graded material.

RESEARCH STUDY

This study investigates the control of deformation in a bending active sheet structure, where the 3D shape is embedded within the internal organisation of the material.



Fig 1. Graded mono-composite sheet

The system is based on the idea that a very simple compressive force might drive a more complex deformation. The sheet is a graded mono-composite which combines two phases of the same thermoplastic, low density polyethelene (LDPE) and ultra high molecular weight polyethelene (UHMWPE). In contrast to most composite systems, which are almost impossible to recycle since it is very difficult to decompose the component materials, recycling is simplified to melting of the composite and reprocessing. The resultant composite retains bending flexibility far beyond that of traditional fibre reinforced composites, is lighter and achieves 3-5 times the strength and stiffness of an unreinforced polymer.

COMPONENT MATERIALS

The mono-composite sheets developed for this study were produced in collaboration with RISØ DTU in Denmark. They combine low density polyethylene (LDPE) and ultra high molecular weight polyethylene (UHMWPE). PE is a thermoplastic polymerized ethylene, and both polymers are already common to building practice. Its different phases can be categorized according to the way that their

molecules relate to one another: chain length, chain branching and molecular density. LDPE has a relatively short molecular chain (a chain of molecules made up of simple repetitive units) with many branches. These branches create many overlaps and tangles with immediate neighbours. This gives it the property of high local resistance but low resistance to bending. UHMWPE has relatively long chains, which no branching. As a result it is much stiffer.

So as to have most influence over the bending behaviour, the LDPE and UHMWPE components of the sheet are organized as a laminate structure. The core of the material is a zone of LDPE while the LDPE and UHMWPE co-exist along the faces. The UHMWPE sheets are laser-cut to achieve the desired material distribution. Each face is divided into quad elements of size 8mm * 8mm, with each element then containing a percentage of the two polymers. The layers are then assembled and the material is consolidated at 135 degrees celsius.

DEVELOPING BEHAVIOUR

To control the bending of the sheets the ratios of LDPE to UHMWPE at each face need to be varied. In order to gauge this effect, several sheets were made up with differing but consistent LDPE to UHMWPE ratios: 50-50, 30-70, 10-90. A simple quad pattern was used, which offset element edges inwards to achieve these ratios geometrically. This pattern was chosen as it ensured sufficient flow through of the LDPE to bond the sheet together. The sheets were pin-jointed and bent in a jig, with the resulting offset bending behaviour used to calibrate the 3D model.

COMPUTING BEHAVIOUR

In the above cases, the geometry of the sheet (length, width, thickness) as well as the loading and restraint conditions, ie. everything that might be representable within a traditional CAD program, is exactly the same, yet each sheet bends uniquely. To simulate this behaviour a digital model was developed within Rhinoceros, using Grasshopper and the finite element analysis tool Karamba.

An underlying parametric model was generated based on the empirical measurement of bending behaviour of an undifferentiated LDPE sheet. The surface of the model was divided into elements of 8mm * 8mm, matching the divisions of the physical sheets. Each element edge was assigned as a beam member within Karamba. Within Karamba, structural elements can be assigned an e-value, which describes the stiffness of a material or its resistance against deformation. For UHMWPE this value is 14000 kN/cm², and for LDPE it is 3000 kN/cm². The properties of the two component polymers are brought separately into the model. These values, as well as the desired volume ratio of each, are taken through a custom Grasshopper node that firstly calculates the resulting e-value for that element at each face, and then taking into account the sandwich structure. The resulting value is applied to the beam

elements that define that element locally. In this way, each element is represented within the structural model via its edges, and the stiffness of each element is designated individually. The parametric model therefore provides a base onto which material is distributed at the meso-scale, and this material information informs the finite element analysis that then determines the macro-scale deformation.

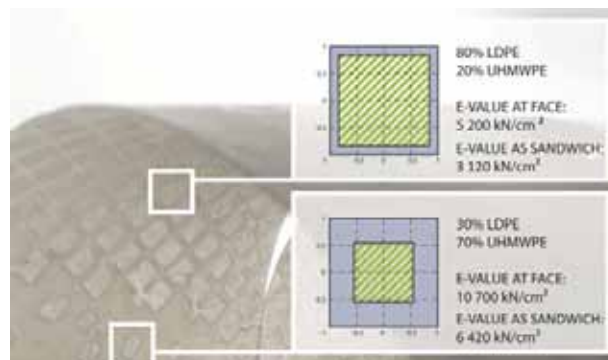


Fig.2 Diagram describing a material element and the distribution of component materials within it



Fig.3 Realised bending behaviour – different responses to the same loading

A direct link was established between the distribution of material on the 3D model and a flat 2D cutting pattern. The pattern could then be laser-cut and the sheet fabricated, enabling a process of calibrating the relationship between digital and physical through empirical testing.

GOAL-BASED MATERIAL DESIGN

The model also implemented a goal-based material design approach that sought to match a desired geometry by optimizing the distribution of material at the micro-scale. Using Grasshopper's inbuilt Genetic Algorithm Galapagos, the performance of different the specification of material combinations could be linked to their performance in meeting a given target surface under bending, allowing for the generation of an optimum combination. It is not within the scope of this paper to describe the genetic algorithm in detail, as the purpose is rather to demonstrate that a goal-based computational design method can be used to drive

material distribution, however the basic steps of the algorithm are as follows:

- 1) The first generation is populated with random individuals
- 2) For each individual in each iteration, the fitness is computed
- 3) The individuals then populate the next generation, based on their fitness, by either 'surviving' or 'mating'. The mating process is controlled through the parameters of population coupling, mate selection, coalescence and mutation
- 4) The process repeats until the maximum number of generations has been reached or until a specific fitness value has been reached.

This approach was tested in two conditions, firstly when the target surface was within the range of possible deformation, and secondly when the target surface was deliberately defined to be unattainable. The surface was divided into 6 material zones, defined by six points and constituting those units on the surface closest to each point. The algorithm was able to adjust the ratio of LDPE and UHMWPE in these zones, and to move the location of each zone. Fitness was measured as the sum distance of each element on the surface to its corresponding element on the target surface. In the first case the genetic algorithm produced results that very closely approximated the target surface, and in the second found an answer that distributed the deviation evenly.

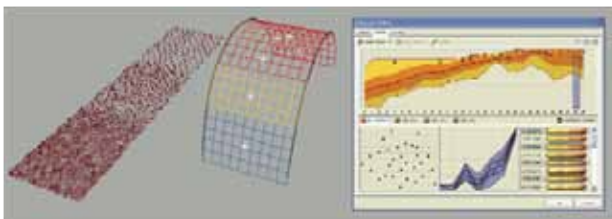


Fig.4 Optimisation model

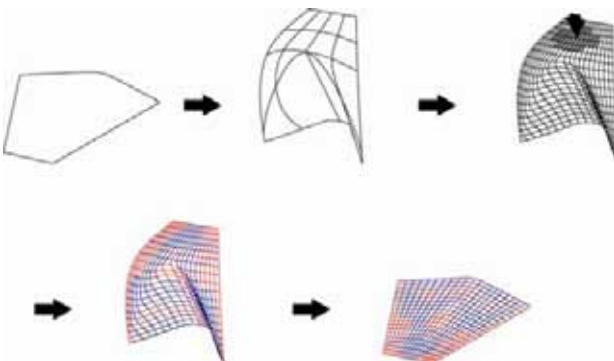


Fig.5 Diagram describing form and analysis

APPLICATION TO THE DESIGN OF A CHAIR

To further explore the distribution of material, this approach was then applied to the design of a chair (PE is a common material for outdoor furniture). As described in *fig. 5*, a flat sheet can be bent to form a chair in such a way that it becomes bending-active. While the material is continuous, the load when someone sits in the chair is not equally distributed, but rather finds the most direct path out. Knowing how tension transfers through the chair makes it possible to distribute higher concentrations of UHMWPE, which is stiffer and has a large capacity for tension, according to load within the material. Materials are distributed so as to counteract the force of the person sitting in the chair.

CONCLUSION

This research explored a way to design and simulate a graded material within a CAD environment, by linking numeric descriptions of meso-scale material distribution to a combined parametric and finite element analysis model. This approach allowed material specification below the level of the component, and for the results to be observed as properties at the level of the component. The implementation has been effective, as demonstrated through the example of a mono-composite sheet, however it is recognized that more complex representations and behaviours as well as detailed material testing, measurement and validation are still required to address real architectural problems.

ACKNOWLEDGEMENTS

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Material Design and Analysis for 3D-printed Fiber-reinforced Cement Polymer Building Components

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ABSTRACT

The creation of building components that can be seen as sustainable, inexpensive, stronger, recyclable, customizable and perhaps even reparable to the environment is an urgent, and critical focus of architectural research. In the U.S. alone, the construction industry produced 143.5 million tons of building-related construction and demolition debris in 2008, and buildings, in their consumption of energy produce more greenhouse gasses than automobiles or industry.

Because the inherent nature of 3D printing opens new possibilities for shaping materials, the process will reshape the way we think about architectural building components. *Digital materiality*, a term coined by Italian and Swiss architects Fabio Gramazio and Matthias Kohler, describes materiality increasingly enriched with digital characteristics where data, material, programming and construction are interwoven (Gramazio and Kohler, 2008). The research aspires towards this classification through the use of parametric modeling tools, analytic software and quantitative and qualitative analysis.

Rapid prototyping, which is the automatic construction of physical objects using additive manufacturing technology, typically employs materials intended for the immediate analysis of form, scale, and tactility. Rarely do the materials used in this process have any long-term value, nor does the process - except in rare cases with expensive metal prototyping - have the ability to create actual and sustainable working products. This research intends to alter this state of affairs by developing methods for 3D printing using concrete for the production of long-lasting performance-based components.

Keywords

Cement, Polymers, 3D Printing, Rapid Prototyping, Fabrication, Materials, Digital Design

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MATERIAL INFORMATION

The word concrete comes from the Latin word "concretus" (meaning compact or condensed), the perfect passive participle of "concreto", from "com-" (together) and "cresco" (to grow). The development of concrete has evolved for over two thousand years. The Romans used quicklime, pozzolana and aggregate or rubble to build concrete structures such as the Pantheon and the Baths at Caracalla. In 1756 John Smeaton rediscovered concrete by mixing hydraulic lime and powdered brick as aggregate. These mixtures produced concrete with a comprehensive strength comparable to the mixes that we use today. The mixes that we most frequently use today include:

Portland cement: which consists of a mixture of oxides of calcium, silicon and aluminum. Portland cement and similar materials are made by heating limestone (a source of calcium) with clay, and grinding this product (called *clinker*) with a source of sulfate (most commonly gypsum).

Water: Combining water with a cementitious material forms a cement paste by the process of hydration.

Aggregates: Fine and coarse aggregates make up the bulk of a concrete mixture. Sand, natural gravel and crushed stone are mainly used for this purpose. Recycled aggregates (from construction, demolition and excavation waste) are increasingly used as partial replacements of natural aggregates, while a number of manufactured aggregates, including air-cooled blast furnace slag and bottom ash are also permitted.

When initially mixed together, Portland cement and water rapidly form a gel, formed of tangled chains of interlocking crystals. These continue to react over time, with the initially fluid gel often aiding in placement by improving workability. As the concrete sets, the chains of crystals join up, and form a rigid structure, gluing the aggregate particles in place. During curing, more of the cement reacts with the residual water (hydration).

Concrete is inherently weak in tension as the cement holding the aggregate can crack. The addition of steel reinforcement to concrete in the 19th century solved this

problem. In addition to adding steel reinforcing bars, we now add steel fibers, glass fiber, or plastic fiber to carry tensile loads. Thereafter the concrete is reinforced to withstand the tensile loads upon it.

The mix for use in the 3D printer is similar yet varies in composition from the traditional mixes used. The traditional processes used vary dramatically, from hand tools to heavy industry, but result in the concrete being placed in a formwork where it cures into a final form. In the case of 3D printing concrete there is no formwork or mould. There is, however, the constraint that all binding particles used in the concrete mix must fit through a 35 Pico liter print head and all cement, aggregate and reinforcement must be smaller than 0.010".

The Portland cement serves the same purpose as it does in a traditional mix, however, other bases, hydrators and adhesives are added to promote hydration and help the object maintain its shape. Additionally, finely chopped binders are used to help reinforce the material and a liquid element is sprayed through the ink jet head to help bind the material.

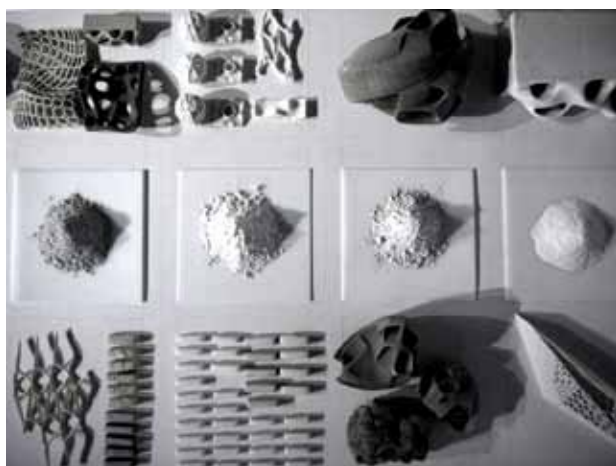


Figure 1. Cement, aggregates, concrete samples, 3D printed models

3D PRINTING

The 3D printer lays down a thin layer of the dry, powdered concrete mix, then using an ink jet sprays the image of one 'slice' of the 3D object or in this case the RCMU (rapid concrete masonry unit), onto the dry mix. The wet parts of each layer hydrate into rock-hard concrete, and the rest remains in a powder form that can be brushed off later. Because concrete cures via a chemical reaction – hydration – no air is required for curing, so the next layer can be deposited immediately.

The cycle of laying down concrete and binder with the binder is repeated over and over, stacking layer upon layer, building up a solid object inside the pile of dry, powdered

concrete mix. The dry concrete mix acts as a support structure during the printing process, so objects may have an undercut which is unseen in traditional concrete casting.

Once the concrete cures enough to handle, which typically takes about 12 hours, the finished object can be lifted out of the powder bed. The dry mix used to support the concrete object during printing can be recycled. Printing an intricate and unique concrete part would only consume a few dollars worth of material, would incur no cost for formwork and very little labor costs. Additionally compared to printing with z corps proprietary blend, the costs are considerably lower. The Z Corp TM polymer / plaster powder, at its cheapest, is \$3 a cubic inch and the 3D printed concrete costs mere fractions of a cent per cubic inch.

CEMENT BASED MEDIA

The initial impetus to work with concrete as a 3D printed material was driven by an installation designed by Ronald Rael and Virginia San Fratello entitled *Earthscrapers*. *Earthscrapers* imagines the potential of employing Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) processes in the construction of a proto-architectural landscape—one where the building material source and the building itself are seamless. The project also imagines a future scenario for the material and the process as a scalable technology—one that also dissolves the role of the architect and builder. We both envisioned printing full-scale buildings and achieving full scale building components with in situ aggregates in a manner that merges the roles of the designer and the geomorphologist.



Figure 2. *Earthscrapers* exhibit demonstrating multi-part assembly systems for 3D Printing

For the *Earthscrapers* exhibit we were uniquely interested in connecting the 3D printed material to the landscape therefore we started by printing various materials including clays, sands and ashes. Ultimately we decided to print a small amount of Portland cement mixed with a large

portion of sand. The resulting concrete prints proved to be very stable, strong and have the effect of looking like earth due to the amount of natural aggregate within the mix.

The plastic nature of both concrete and 3D printing offer up a powerful material solution to recent generative design processes in architecture, which often feature organic, doubly curved surfaces and complex ornamentation. The *Earthscrapers* exhibit explored a range of complexly curved forms. It also explored thinness and attempted to push the limits in terms of extracting thin surfaces and thin structural elements from the printer bed. Several of the complexly curved, fiber reinforced concrete prints were easily 1/16 of an inch thick which would be very difficult, if not impossible, to cast using traditional methods of mould making. Making the 3D printed models and objects that were on display in the *Earthscrapper* exhibit was an active process where software, geometry, material, fabrication and production were simultaneously linked. The complexity of form was limited by thinness and slump. If the form were not allowed to cure in the bed for at least 12 hours the concrete object would fail. Additionally, the success of the mix depended on the amount of binder being laid down at each successive interval. For example, if the binder was sprayed at full capacity the concrete print would slump therefore the binder level should be set at .75.

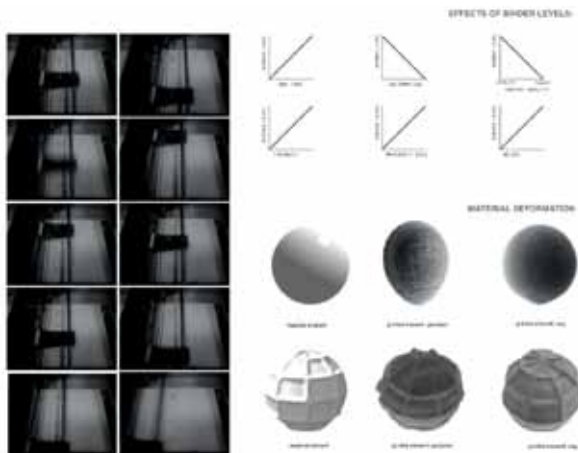


Figure 4. Binder level tests

The designs for the models and objects that we printed for the *Earthscrapers* exhibit were based on the exploration of complex geometries. We used software applications such as Top Mod that allowed us to dynamically change the topology of 2-manifold polygonal meshes to explore structural skins. Also used were Blender and Modo to explore texturing, twisting and deformed surfaces and Rhinoceros to explore part to whole relationships, paneling and how these 3D printed pieces might interlock and connect.

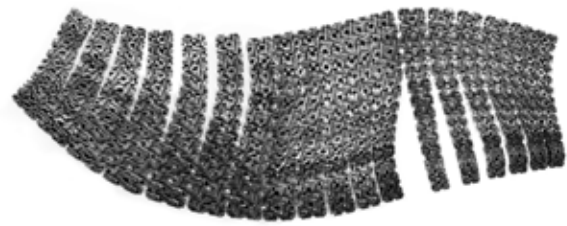


Figure 5. Photo of models that study unfolded relationships

The 3D printed models were placed in a landscape made of the same aggregate in order to simulate environments where desertification, erosion, mining and dredging have shaped the landscape. These places have become the theoretical material sources, sites and contexts for the forms and spaces created in the proposal.

BUILDING COMPONENTS

The production of part to whole assemblies for the *Earthscrapers* exhibit led us to initiate new 3D printing research, involving the development of non-standard geometric architectural concrete masonry units that are weather proof, solar responsive, store or filter water, hold plant life, contain embedded technologies, create insulation barriers between interior and exterior surfaces, dissipate seismic forces and many other possibilities offered by this nascent and potent process. For the first set of prototypes, we chose to develop building units that are weather proof and porous to the extent that they have apertures in them that can direct and filter light and are able to support vegetation. The units are applied to a doubly curved polysurface that acts as a building enclosure. Each unit is then panelized to the surface creating an assembly of variegated and unique parts. The units are designed to be fastened to each other and the final structure will be completely self-supporting and will not require secondary scaffolding. The final product is the scale of a room and is composed of 1200 3D printed concrete units.

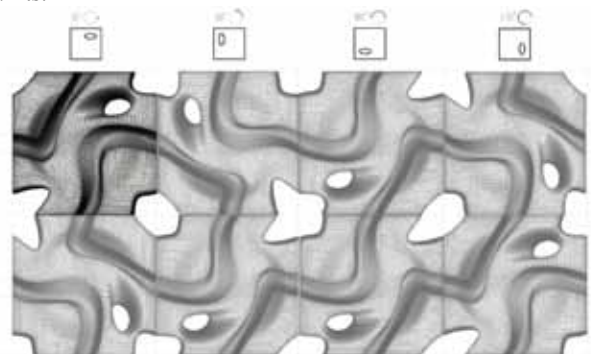


Figure 6. *Karakusa* multiple-part assembly of tiles

IMPACTS

One of the benefits of this research is that through rapid manufacturing, differentiated geometries can be created that would be impossible to create by hand or require expensive machinery to produce or reproduce. Because the process requires no formwork, concrete components can now be *mass-customized and contextualized*, employing the flexibility of CAM systems, rather than mass-produced, allowing design parameters to be quickly changed and tested without incurring costs associated with labor and retooling. Thus, the process bypasses several of the steps involved in traditional pre-cast concrete production, which include form making, extraction, etc., making it possible to go directly from file to fabrication.



Figure 7. 3D printed concrete polymer multiple-part assembly

Another benefit is the greatly reduced material cost. If the cost of molding and formwork is 35 to 60 percent of the cost of a concrete structure, then 3D printing in concrete offers tremendous cost saving to the construction industry. A third benefit of 3D printing concrete is that the excess cement and aggregate can be recycled. Thus the 3D printing of durable components raises questions regarding expense, durability, speed and size.

EXPENSE

Currently, all commercial forms of rapid prototyping are incredibly expensive. This expense comes in three forms—equipment, material, binder and time. While much innovation is being developed to make rapid prototyping equipment more accessible, the costs of consumer and professional grade rapid prototyping equipment is generally in the 10s of thousands of dollars. Material expense is also considerable. All commercially available equipment offers its own proprietary materials. These materials are generally exorbitantly expensive. Additionally, there is generally a

very limited material palette for use with each piece of equipment, making the use of multiple materials even more economically unrealistic since if one was to consider a material assembly of different materials it would require multiple machines from different manufacturers. In many cases, materials are also meant for prototyping only and long-term viability of a prototype is unlikely. In many cases, additional materials are required for the production of a rapid prototyped object. Binders, which aid in adhering materials together or post-processing materials to harden or finish a material are also often proprietary and an added expense. Additionally, extraction of materials also requires solutions that wash away supporting structures or several man-hours are required to excavate, extract or remove parts. If we consider that time = money, the slowness of rapid prototyping, which can take several hours or days to produce a single object, means that only a limited number of objects can be produced given the availability of resources (numbers of machines, availability of materials and availability of time).

DURABILITY

Most rapid prototyping materials in use today are considered only for short term examination, analysis and utilization. In many cases, the materials have no structural durability. They are made of friable powders that are laminated with glues or binders. Many of the more durable plastics are not resistant to ultra-violet light or can not withstand high temperatures. Metals and glass must be sintered at low temperatures and can be porous and fragile. Methods to strengthen these materials are also expensive. These limitations makes the transition from prototyping to manufacturing improbable given many of the current technologies, materials and processes.

SPEED

While the term rapid prototyping is suggestive of the speed in which designers can move from CAD to the visualization of a physical object, the production of a single rapid prototyped object, when weighed against the possibility of manufacturing, can be quite slow. In most cases, a single object can take several hours, if not multiple days, to produce. The extraction of materials can also be time intensive. Fragile parts removed from supporting structures or that are buried within the materials used in powder form can be time-consuming and laborious. As stated previously, the process often does not end when it is removed from the machine that produced it. Post-processing, which involves the stabilization, reinforcing or strengthening of the rapid prototyped object also can be time consuming due to the labor involved and the amount of time required for parts to set.

SIZE

While rapid prototyping technologies allow for the production of larger objects, the limitations of expense, speed and durability are still an issue. By increasing the size of production, expense and time are obviously increased putting the potential for manufacturing actual, usable objects at a greater distance. Increased sizes of equipment and increased amount of materials mean increased expenses as well. The production of larger objects means slower production times and the added cost of machine and man-hours in the production process. Size issues demand an obvious increase in material performance, since larger size parts must be to a certain degree, self-supporting. Larger spaces required by this process also represent pressures on resources.

PERFORMANCE ASSESSMENTS

The use of an organic adhesive in the concrete mix prevents the cement from joining with the water and slows the hydration of the cement; in most cases this is considered a drawback. The solution may well be to introduce an alcohol-based binder to the mix, which has had good results in initial tests as this additive is a water-soluble synthetic polymer that has high adhesive and emulsifying properties and high tensile strength. Ideally it will not only help the mix cure more rapidly but also cause it to be denser and have greater flexural strength.

A further development in seeking to strengthen the materials involves an infiltration process that appears to strengthen the units in two ways. The infiltration hardens the material by adding a secondary hardening component that joins the fibers to the concrete matrix while also simultaneously hydrating the material. The result is a hybrid concrete polymer. This infiltration has resulted in a remarkably strong product from a common rapid prototyping process. The highest performance thus far has been realized using a combination of fiber reinforced and infiltrated material with fiber mesh reinforcements running in the “Y” axis of the 3D printers’ build bed (see chart below). The fiber strands are oriented by the direction of the roller of the 3D printer. The unit failed at 4537 PSI at 14 days, which exceeds the minimum requirements of traditional concrete at 28 days.

The capability to 3D print at the scale of the building is gaining momentum and is certain to occur. Dr. Behrokh Khoshnevis, of the University of Southern California has developed a different printing technique called Contour Crafting (Khoshnevis, 2008). Contour crafting is a layered fabrication technology that has potential for automating the construction of whole structures as well as sub-components. Using this process, a single house or a colony of houses, each with possibly a different design, may be automatically constructed in a single run, embedded in each

house are all the conduits for electrical, plumbing and air-conditioning. They have recently collaborated with Caterpillar to fabricate a 6-foot wall.

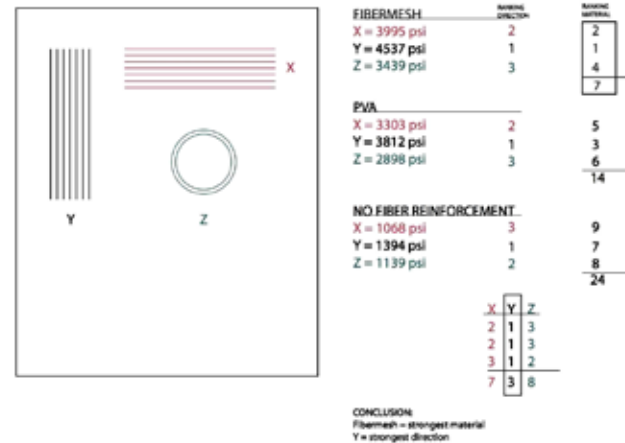


Figure 8. Chart showing strength testing results

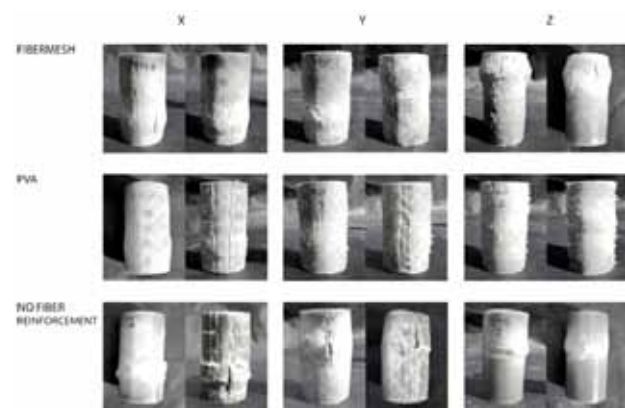


Figure 9. Photographs of structural tests

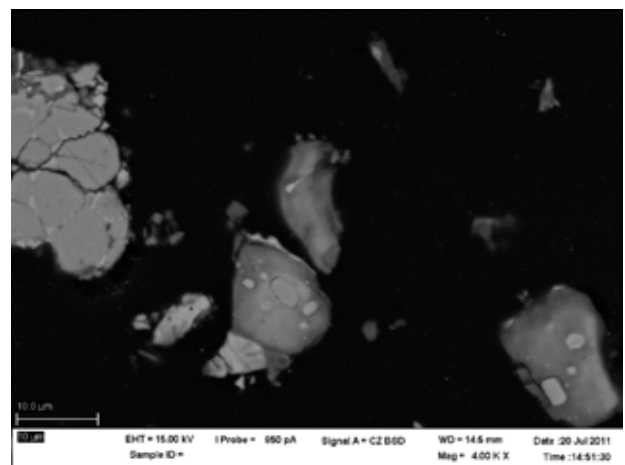


Figure 10. Electron microscope scan of cement particles



Figure 11. Completed cement polymer bench

Rael and San Fratello are currently collaborating with Enrico Dini of D-Shape, to develop materials for 3D printing on an architectural scale. Dini is the inventor of the largest 3D printer in the world, which is a 10' x 10' x 10' 3D stereolithographic printer that creates models entirely out of artificial sandstone using CAD-CAE modeling technologies and CAD-CAM software to control the plotter. The printing proceeds in 5-10mm layer segments and, in the end, produces a structure that has strength characteristics reminiscent of standard Portland cement.

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Listener: a Probe into Information Based Material Specification

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ABSTRACT

This paper presents the thinking and making of the architectural research probe Listener. Developed as an interdisciplinary collaboration between textile design and architecture, Listener explores how information based fabrication technologies are challenging the material practices of architecture. The paper investigates how textile design can be understood as a model for architectural production providing new strategies for material specification and allowing the thinking of material as inherently variegated and performative. The paper traces the two fold information based strategies present in the Listener project. Firstly, the paper presents the design strategy leading to the development of bespoke interfaces between parametric design and Computer Numerically Controller (CNC) based textile fabrication. Secondly, by integrating structural and actuated materials the paper presents the making of a new class of materials that are computationally defined as well as controlled. The paper asks: what happens as architectural practice incorporates material design, how do we conceive and use variegated materials and how can we develop relevant concepts and tools for such material specification?

Keywords

Performing materials, digital fabrication, architecture, textiles

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Next Generation Materials

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ABSTRACT

Through the broader availability and market presence of smart materials, architects and designers began conceptualizing and introducing them into the built environment. Looking closer at the history of material use in building and construction, the current quest for standardized and homogeneous composites that conform with digital design and fabrication methods and the fact that we're trying to categorize and treat these new materials the same way as traditional materials or are using them to replace established technologies, raises the question whether we're not misunderstanding some of the inherent material properties and the unprecedented possibilities. Setting this into the context of the demands of new, young generations, who are seeking for multi-dimensional, technologically loaded environments where connectedness and flexibility become key elements, conventional architectural approaches to design rigid, stable and everlasting structures seem insufficient. This paper discusses these two main aspects and proposes a different approach to architectural materiality, which could lead to the creation of highly adoptable spaces in regards to the needs of our future citizen. The theoretical part is concluded with three recent projects that were realized at the Chair for Computer Aided Architectural Design (CAAD), ETH Zürich, within the last twelve months.

Keywords

Smart Materials, Material History, Generations, Technology

SOLIDS

Natural Materials

In "The ten books on architecture" Vitruvius states that built structures should embody the three qualities of "firmitatis, utilitatis, venustatis", stability, usefulness and beauty [34]. This classical definition of a rigid, permanent, enduring and solid construction also appears in many other architectural publications. In 1570 Andrea Palladio wrote: "Durability will be guaranteed when all the walls are plumb vertical, thicker below than above the other" so that "solid is above solid and void above void. Beauty will derive from a graceful shape and the relationship of the whole to the

parts [27]." 100 years later the French architect Francois Blondel mentioned in his "cours d'architecture": "Architecture is the art of building well. A building is called good, when it is solid, convenient, healthy and pleasing [6]." A similar position is also expressed in Jean Baptiste Rondelet's "Theoretical and Practical Treatise on the Art of Building" (1802) where he claims that architecture is not an art but a science and its essential purpose is to form a solid and modest construction [10]. Following this line of French argumentation Corbusier published in 1923: "You employ stone, wood and concrete and with these materials you build houses and palaces. That is construction [11]."

The fundamental connection between weight, solidity and construction as well as the pragmatic use of building materials were decisive for architectural design prior to the Industrial Revolution. Form was seen as a pure expression of intellect and materials were solely a manifestation of those ideas into physical artifacts. Materials were subordinate to design and were chosen due to their local availability, their properties to meet certain structural requirements or simply for their visual and aesthetic appearance. The strong bond between regional material resources, the resulting means for construction and the hence generated forms and spaces influenced and limited each other. Design was defined through functional and formal demands and the craftsmen's understanding of materials to use and exploit their qualities. Master masons, who had gained that knowledge through lifelong experience, education and thorough observation, not only designed the building and all its ornamental details but also developed tools to cut stones and wood or molds to form bricks from clay. Over centuries they merged the role of architects, contractors, administrators and technical supervisors into one person and were utterly responsible for passing their knowledge on to their successors.

Engineered Materials

With Industrialization and the possibility to mass produce materials and dispatch them over large distances via newly developed ways of transportation, like canals or railways, the importance of materials changed from being secondary to architectural demands to "expand functional performance and open up new formal responses" [3]. Gottfried Semper was one of the first who argued in his publications for the so-called "Truth to materials", the nature of materials should be exposed and applied where they were most appropriate [22]. Architects like Adolf

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Loos or Frank Lloyd Wright supported Semper's theories and propagated the development of form in accordance to material [16].

Instead of being restricted to natural resources and a long acquired understanding of material properties, architects and builders of the Industrial Revolution were introduced to engineered materials and steam-powered machines which improved productivity and reduced costs. Thus traditional materials like bricks could be manufactured in consistent quality and large quantities, but even more important new developments, such as cast iron, and later on steel, exhibited completely new structural properties and enabled much lighter, stronger and especially higher buildings. Advancements in glass making enabled the creation of large panes without interruption and freed interior space planning and exterior fenestration. One of the earliest examples to take advantage of sheet glass was Richard Turner and Decimus Burton's Palm House at Kew Gardens, built from 1844 – 1848. Joseph Paxton drove these new possibilities of the combination of glass and steel to another extreme. The glazed perimeter of his Crystal Palace, built for the Great London Exhibition of 1851, was uninterrupted, except for the three entrance porches, and was produced within only eight days [13]. Based on the development of Portland Cement, whose thermal expansion properties are almost identical to those of iron and steel, reinforced concrete emerged in the late 19th century [33]. The high tensile strength of iron and steel, enclosed in cheap and fireproof concrete resulted in a strong and economical structural member that could be shaped in almost any desired form. Combined with innovative construction techniques, like steel frames or curtain wall systems, these new materials and the standardization of traditional materials gave birth to Modern Architecture.

Synthetic Materials

With the invention of plastics at the end of the 19th and beginning of 20th century the first entirely artificial substance entered the realms of architectural materiality. This outcome of chemical processes, which unifies lightness, transparency, stability, insulation and deformability, greatly influenced the imagination of artists and architects of the postwar and enabled them to envision an architectural reality which did not need to remain static and within the limited properties of traditional building materials but instead could react, adjust and even evolve with and within the environment [17]. As a result of this newly developed world of unlimited, biomorphic forms and utopian urban concepts of a better tomorrow, a new breed of architectural visionaries emerged, which – although only for a short period of time – revolutionized the architectural domain [14]. Buckminster-Fuller was one of the first to propose plastic in his mobile and eco-friendly scenarios, like the Dymaxion House (1927), the Wichita House (1945) or the iconic Montreal Biosphere for the Expo 1967, which was clad in acrylic cells and became a symbol for the technological domination of nature. Another

remarkable pioneer during these times was Austrian-American architect Friedrich Kiesler, who was reaching beyond formal aspects and, with his "endless house" study, aimed to create a spatial symbiosis between man, nature and technology [7]. As a physical manifestation of his ideas he designed the Space House in 1933 for the New Yorker Company Modernage Furniture, which was supposed to be cast entirely in plastics to create a fluid transition between floors, walls, columns and ceilings.

Driven by a euphoric decision to abandon traditional practice, a fascination for space travel and a strong believe in technological progress and the usage of uncommon materials, artistic collectives like Archigram (1960), E.A.T. (1967), Haus Rucker Co. (1967), Coop Himmelb(l)au (1968) or AntFarm (1968) formed around the globe and developed architectural concepts based on individualism and self expression. For them architecture had to go beyond the creation of isolated structures and tend towards environmentally and organically funded design. They relied on a future of abundant resources and developed visionary urban scenarios and large spatial experiments that didn't need to remain within the limits of established norms but allow for a more flexible and independent living [28].

Digital Materials

The constant seek for standardized materials and homogeneous fabrication and treatment methods have culminated in today's advancements of CAD/CAM (Computer Aided Design/ Computer Aided Manufacturing) technologies. Architecture is generated within virtual machines and the only boundaries seem to be computational power or the limits of software. Any imaginable form can be generated, endlessly and dynamically reshaped and the material, as form determining factor, is replaced through simulated physical, biological or structural processes. More recently, the use of rule based systems and algorithmic computation to create form and space, allows the introduction of naturally inspired processes, like self organization, self assembly, swarm behaviour, agent based systems or evolutionary strategies. Although these methods create shapes and designs that were formerly unimaginable, the importance of material as design influencing factor is, if at all, only treated on a digital level and thus shifted back to the end of the design process where it undergoes solidification within production. As a result of these advancements in computer aided design and fabrication methods, contemporary architects think of materials as immaterial components, which can be chosen from a design palette and, similar to the use of textures in 3D renderings, applied as visual and compositional architectural elements. This trend of categorizing and sorting materials into certain sets of quantifiable qualities is represented in the large amount of material databases, libraries and catalogues that appear in print, online and physically in almost every major city.

Although these new approaches in generating and fabricating architecture are dubbed non-standard, emergent

or even morphogenetic, once the design process is over they are still manifested in solid and static forms, with materials completely generalized and de-contextualized. The dynamic process of architectural design is frozen into inanimate (non-) Euclidian shapes and even natural components, like wood or stone, are treated as their artificial counterparts and post-processed with the same techniques and machines.

THE ALPHA DILEMMA

Generalized Space

Architecture is omnipresent and everywhere. As we spend more than 90 % of our time within enclosed spaces [18] and about 15 hours per day at home [8], buildings have to allow for an immense diversity of occupations, uses and activities. They need to provide shelter, space and comfort and at the same time be aesthetically pleasing and visually appealing. Besides functional properties, rather psychological qualities of buildings are the provision of privacy, security and intimacy. Similarly decisive is the ethical or cultural importance of buildings and their impact on trends and tendencies in society and community. But the same way that built structures influence how we behave, move and interact within our environment, culture, society and religion shape the form and function of architecture and the art of its occupation. For example the necessary amount of intimate, personal, social or public space to feel comfortable varies among different cultures likewise to the importance of private or semi-private zones within the individual home. This results in a multitude of spatial layouts and building types, each representative for its nation, geographical location or climatic region.

Usually not considered in architectural design is the difference in spatial demands for co-existing generations. Although architectural style as well as construction and materials changed over time it is still taken for granted that spatial generalization and building standards allow people of all ages to feel at ease in the same rooms and houses. In public areas this issue is normally tackled through an abundance of norms and codes for accessibility and safety. In case of private spaces a temporal adaption or interior upgrade helps to conform to the needs of occupants. Most of these amendments to existing buildings and design influencing factors to new buildings are aiming for a general freedom from barriers based on decreased physical abilities or reduced mobility of senior citizen. Not so much considered are the needs of the younger generations. Even more striking is, that it is generally assumed that values, positions, priorities and needs of youths today are equal to the ones of the elderly when they were adolescent. Obviously juveniles of all generations exhibit similar characteristics such as exploring their limits, challenging the status quo, or an experimental lifestyle. It is simplistic though to standardize this knowledge, as the influence of culture and social events on behavior, attitude and character is much stronger than the impact of age [23]. The life

influencing factors of today's teenagers, children and infants, like ubiquitous technology, apotheosis of pop culture, global political events and an average wealth, only to name a few, has ensured that they are substantially distinct from their predecessors.

Generation Alpha

After commonly used expressions like Generation X, Y and even Z, babies born from 2010 will be known as Generation Alpha. Obviously there is only little or none empirical data available to evaluate the demands of these still very young people. Nevertheless there can be some predictions made based on statistical surveys on Generation Y (children born from 1980 – 1994 [19], about 25.36% [32] of world population), also known as the Millennials, as well as recent studies on the characteristics and expectations of Generation Z (children born between 1995 and 2010 [25], about 26.28% [32] of world population).

Generation Y grew up in a media-saturated, brand conscious environment, very different to previous generations, and their childhood was strongly influenced by the birth of digital technologies. They witnessed the beginning of the Internet, Email, Cable TV, the introduction of the Personal Computer and the Laptop. They are very quick in adapting to new developments and are familiar with mobile devices, digital cameras, e-commerce, social networking and online Gaming. They trust in the development of new technologies and believe they make life easier, bring family and friends closer together and allow them to use their time more efficiently [20]. While sending an average of 20 text messages per day [21] and ranking communication through social networking sites almost as important as face-to-face exchange [15], they use the Internet for entertainment, information, shopping and self-expression. As they personally experienced the evolution of digital technologies, they have a certain level of abstraction towards their use, advantages and disadvantages and know how to apply them efficiently and purposeful. Still they cannot imagine ever being without them again.

Generation Z are presently 2 to 16 years old. They were born into smaller families with the fewest siblings of any era and will live longer than any other generation in history. While parts of Generation Y still have a faint recollection of times before mobile phones and Internet, Generation Z are true digital natives. Having grown up on social media, text messaging, smart phones, Google and Wikipedia, they don't consider the Internet to be the greatest invention of mankind as it has always been there for them. They are maturing publicly online, create web content with ease, have an inexorable attitude towards blogging and online publishing and, while multitasking, place more value on speed than on accuracy. The Australian Bureau of Statistics estimates, that about 95% of Australian kids use a computer and about 64% of them have access to the Internet [31]. eMarketer assumes that by

the end of this year 96% of US teens between 12 and 17 will access the internet at least once a month and 70% visit Facebook weekly [12]. Besides social networking, the main reason for spending time online is Gaming, marking their second most important recreational activity after watching television. A global study, conducted in June 2010 among the users of teen online community Habbo Hotel, which as of August 2011 had about 230.000.000 registered members [29], further revealed the importance of the internet and its growing influence on today's youth [30]. Whereas TV and radio remain substantial, over 55% believe that digital content, in form of e-books, websites or newsletters, will soon replace traditional print media and 34% were supporting the idea of expanding our linguistic usage with the informal language developed in chat and text messaging. Furthermore over a third of the survey participants felt that in the future physical meetings could be reduced and instead superseded by online interaction within virtual space, which most likely would be utilized at home, proposing the creation of a virtual home to exchange with friends and family rather than visiting a virtual world.

Generation Alpha currently makes up 3.5% of the world population [9], will reach 9% by the end of 2014 [32] and according to Australian National University head of demographics Peter McDonald might become our biggest generation yet [1]. Born in a time of tremendous globalization and ethical diversity, they most likely will be the most formally educated generation ever, meaning that they go to school earlier and study longer. Due to a large shift in the labor market, when the ageing population hits its peak and starts leaving the workforce, they're expected to work more, follow a multitude of different careers and change their employer more frequently. Being the children of older and wealthier parents (the average age of women having their first baby shifted from 25 in 1982 to 31 today) [24], they will have earlier and more contact with entertainment devices and digital technologies. It is anticipated that they will become more materialistic and technology-focused than any of their preceding generations and might not even remember the existence of some of our common technologies, like landline phones, MP3 players or even flash drives [4]. Increased consumerism will make products cheaper, more temporary and lightness, simplicity, flexibility and interconnectivity will become key properties. They will own less physical objects at a time but change them more frequently. Great amounts of individualized data will be stored remotely and can be accessed constantly and anywhere. The developments in technology that we're going to have will continue and change even faster, leading to a generation that will approach things very differently than their predecessors.

Next Generation Architecture

To be prepared for this new lifestyle architecture has to allow for the incorporation, unification and translation of these functions into spatial compositions. As the largest

amount of people will be living in urban agglomerations space will become more precious and expensive. Rooms and buildings have to become flexible, easily adoptable and remain upgradable to enable a multitude of people to live in close neighborhood and accommodate fast and constant shifts in occupation. Individualization and personification will mostly happen on a digital level, through data gained from biometric sensors that is further processed by intelligent systems, and propel the possession of less physical artifacts and the creation of adaptive buildings that learn over time. Smaller but more technologically gentrified spaces, that combine various areas of living and provide a multitude of usages, will become key to enable a denser community and the unification of workplace and home. Architectures primary functions will have to be extended to become multifunctional display and input devices and guarantee the coexistence of virtuality and reality under the same roof. While digital and physical worlds merge, the importance of the home as a safe place of retreat will have to be extended to protect privacy and valuables from cyber attacks and online threats. With all these technologies at the disposal comes the risk of a sedentary lifestyle, resulting obesity and more chronic illnesses. Architecture will not only have to integrate new technologies but also do this in a fundamentally different way than we're used to.

NEXT GENERATION MATERIALS

Smart Materials

A current technological development in architecture focuses on the incorporation of various degrees of highly advanced systems, to create sustainable and eco-friendly buildings, that intelligently control and react to the environment and their inhabitants. Digital components to control lighting, shading, ventilation or temperature, as well as home automation systems have become standard elements in contemporary design practice. An even more critical role is assigned to the use of smart materials, which are already celebrated as the answer for the 21st. century's technological needs [2].

Smart or intelligent materials are generally defined as materials which possess one or more properties that are capable of sensing the environment and actively responding to it in a controlled way. Especially when it comes to active structures, they have obvious advantages compared to standard actuators. Their unique properties allow them to alter their appearance or performance without a necessary change in size or scale. Further they aren't mechanically complex, so a separation between structure and driving actuator can be avoided.

Due to these capabilities, the improved commercial availability and increased presence in other fields, like the automotive or textile industry, architects started including them in their designs and are speculating on how they could replace more conventional materials and enhance buildings, which are always confronted with transient needs.

Following the current trend of material use in architecture, they are being evaluated and categorized to fit into

standardized design palettes and catalogues. It seems to be ignored though that these materials are fundamentally different, as their properties are variable and not static. Trying to incorporate them next to traditional materials and fixing them in between rigid structures, degrades the unique possibilities they offer. Similarly using them to replace active components within mechanical systems, places them on the same level as their established counterparts. Instead of treating them the way we're used to treat materials and hiding them within solid enclosures, we should focus on the distinct characteristics they inherit and emphasize their values. Instead of using and restricting them to meet a certain goal or design, we should evaluate what the materials are capable of and expressively expose their qualities. Instead of analyzing and explaining them in comparison to standard materials, we need to understand that the term material doesn't really apply to them, as they cannot be grasped in a traditional way. Only when we start accepting that these composites propose a radical departure from what we are familiar with, when we start developing concepts based on the new opportunities they offer and when we start thinking out of the box, not limited to established standards and systems, we will be able to create a non-mechanistic, organically [26] inspired architecture that extends formal and structural adaption to a new understanding of materiality and leads to futuristic, soft, flexible and sensitive spaces to accommodate the needs of our future generations.

Materiability

In the research that we're currently performing at the Chair for Computer Aided Architectural Design (CAAD), ETH Zürich, we're analyzing the specific material properties and orchestrate them in an architectural scale and spatial context. Through direct physical contact with the materials and collaborations with professionals in the domain, we explore their strengths and limits. In the field of shape changing materials we have worked with electroactive polymers, which stand out due to their large active deformation potential, low density, improved resilience and immediate response, and in the area of light-emitting composites, we have used electro-luminescent screens, which are intriguing because of their thinness, flexibility and perfectly homogeneous glow across their surface. The following projects were developed together with or from students and form part of a larger ongoing research initiative.

ShapeShift

vimeo.com/materiability/shapeshift

'ShapeShift' proposes a new possibility of architectural materialization and 'organic' kinetics. It explored the potential application of electroactive polymers (EAP) at an architectural scale.

EAPs are polymer-based actuators that convert electrical power into kinetic force and change their shape correspondingly. In the field of "active materials" EAPs

stand out due to their large deformation potential, high response speed, low density and improved resilience. They are capable of strains up to 380 %, extremely flexible, light, thin, transparent and can basically be tailored to any size or shape [5].

In 'ShapeShift' these distinctive material properties were used beyond conventional actuator replacement and became orchestrated for their aesthetic qualities. The component-based form resulted from the material's desire to return into its original shape combined with structural frames that were developed to allow an appropriate degree of flexibility. This minimum energy structure retained a variable stiffness, which allowed for a variety of deformations within a given range. Each element consisted of a thin layer of stretched elastomeric film that was attached to an acrylic frame and sandwiched between two compliant electrodes. This was achieved through coating both sides of the film with conductive powder and insulating them with liquid silicon. Once a high DC voltage in the range of several kilovolts was applied, electrical charges moved from one electrode to the other and the film was squeezed in its thickness direction, which lead to a planar expansion. After actuation the EAP became thinner and its surface area increased. As the membranes were attached to flexible frames, due to the initial pre-stretching, the frame bent when the material was in its relaxed state. After the voltage was applied, the material expanded, and the components flattened out. Parallel to the design of single elements, efforts in structural arrangements and tessellations were performed. Early investigations focused on static systems, but after a number of experiments the interest moved towards dynamic configurations. No static backbones were necessary as individual components got connected to each other to produce self-supporting forms. As with the single units, the dynamic structures achieved their final shape from the relationship of the EAP to the frame and their interdependent connections. Through direct component-to-component linkages an added layer of complexity was achieved. Each entity had an influence on the form and movement of its neighbours, and therefore, on the structure as a whole.



The final prototype of 'ShapeShift' consisted of 36 individual EAP elements.

This concept of independent devices networked together and affecting each other's behaviour, can easily be merged with computational approaches to collaborative intelligence and self-organization. In combination with other transformational materials, sensors and embedded control units, the creation of complex and responsive environments that can dynamically adapt to external influences and physically respond to human input becomes possible.

Material Animation

vimeo.com/materiability/materialanimation

Material Animation was a kinetic light installation, made from laser-cut electroluminescent (EL) foils, which sensed location, number and velocity of human occupants and responded through a multitude of wirelessly networked components to encourage further interaction. EL foils are extremely thin, flexible and lightweight screens, which emit a homogeneous cold light across their surface without the need for additional infrastructure.

The experiment was situated in three interconnected rooms, each reflecting a different theme and approach to physically animate the material in an architectural context.

'Vapor' created a fluid space consisting of eight floating elements that were expanding and contracting in response to human interaction. Generative design processes helped to maximize the three-dimensional form, which was created through the way that two A4 sheets were cut and combined. 'Open Wires' aimed to create an environment based on lighted, ephemeral and unpredictable three-dimensional shapes. The system consisted of 31 EL strips that revolved and flickered in high speed. The visual impact was affected by both the turning speed of the motors and the on/off state of the EL strips. 'Insomnia' focused on the flexibility, thinness and consistent illumination of the material. These properties were used to back light two optical animations based on moiré patterns. The structure consisted of an EL layer, printed black and white pictures and a striped pattern, which slid horizontally.



'Vapor' focused on the lightness of the material and the ability to create three-dimensional forms by cutting it.

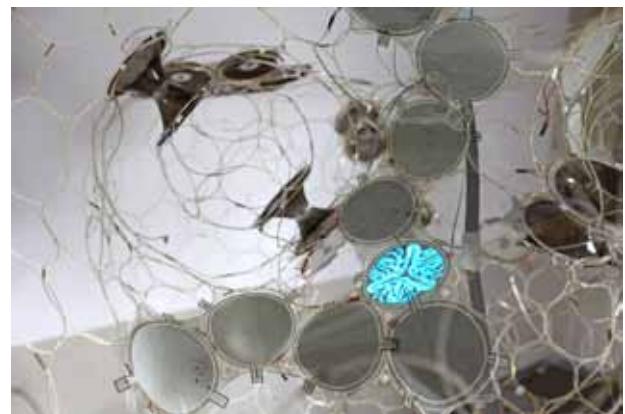
Each room was equipped with one Microsoft Kinect Camera, which sensed the amount of people, their position,

movement and speed, and if more than two people were in a room, also the area they occupied. Every installation was linked to a computer, which communicated wirelessly with a remote server that was responsible for data distribution and choreographed performance of the spaces. After the information had been compiled on the server individual data packages were sent back for further interpretation on the local PC. This exchange of data packages was used to organize the dynamic variation of elementary responses. Serial communication was used to send signals from the remote network to decentralized Arduino Microcontrollers, which in turn controlled servo and DC motors to move the elements and transistor/ relay circuits to switch EL foils.

Actuated Matter

vimeo.com/materiability/actuatedmatter

The Actuated Matter Workshop forms part of a recently started research initiative – a collaboration between the Zurich University of the Arts and the ETH Zürich's Chair for Computer Aided Architectural Design – that explores the application of smart materials in architecture with respect to their ability to transform architecture into an "Emotive Environment", a space that relates to its inhabitants in an emotive and responsive way. The focus is placed on the capabilities and limitations of materials themselves in generating kinetic, visual and acoustic feedback. Our goal is to endow artificial spaces with some of the qualities of a natural environment in which perceptual, behavioral, emotional and social processes are interrelated and arise from its intrinsic properties. Natural environments grow, evolve and internalize the history of the actions and situations that occur within them, whereas technological systems tend toward perfection, predictability and permanence. The question arises on how we could incorporate aspects of organic systems within the new materials and new architectures?



The 'Actuated Matter Workshop' merged self-made thin EL screens, flexible audio panels and EAP elements into a lightweight spatial installation.

The Actuated Matter Workshop took place at Zurich University of the Arts from July 25. - 29. 2011 and was co-run with London based Loop.pH design studio. During the

workshop the twenty international participants developed a speculative model for membrane structures that exhibit properties of sensitivity, resilience, and decay. By physically engaging with the behaviors of active materials, they experimented with the threshold between the electronic and mechanic, the analog and the digital. The workshop followed a do-it-yourself approach and led to the development of sonic, luminous and moving modules that populated and activated the environment. The main structure was based on a three-dimensional ecology of interlinked loops, made from optical fibers, that formed a lightweight system with enough flexibility to become actuated but sufficient stiffness to support a multitude of components. The production of the active elements, electroluminescent screens, electro-active polymers and flexible audio panels, was strongly driven by the curiosity and engagement of an interdisciplinary team of participants who had little or no previous experience of working with such materials. The workshop showed that highly sophisticated materials and structures could be emerge through participatory and collaborative strategies, thus reflecting our goal of developing an alternative, less rigid architecture of the future as a more connected, interlaced, entangled, responsive and responsible world.

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Knitting Moves: Bio-inspired Transformable Textiles for Knitted Architecture

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ABSTRACT

This paper reports on postgraduate research exploring the use of biomimetic design principles in the design and development of responsive knitted textiles for architecture. Central to the investigation is the relationship between the inherent properties of natural materials and weft knit structure. The research suggests that it is through the manipulation of these elements that innovation in responsive design can occur. This research sits at the intersection of materials innovation and smart textile design. Whilst current research remains speculative in terms of applications within architecture, conclusions discuss potential impact of the work.

Keywords

Knit, biomimetics, responsive materials, architecture, smart textiles

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Visual Bio-composites - Establishing New Conditions for an Old Material

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ABSTRACT

The attention of most traditional fiber composites research goes to optimizing the mechanical properties as the typical applications for fiber composites are found in the transportation and wind turbine industries, where the necessity of light, strong and form-flexible materials helps to optimize the strength and shape in order to increase the efficiency of the systems.

It is believed that the market potential for fiber composites can increase by recognizing the existence and consequence of a visual value, regarded as just as important as traditional properties. This article includes two studies within the emerging field of visual and bio-composites and aims to establish a foundation for changing the perception of fiber composites and its applications.

Keywords

Fiber composites, sustainability, materials innovation, functional materials, aesthetics, building materials, textiles in architecture.

INTRODUCTION

A fiber composite is a material consisting of two separate components; a fiber (or textile) and a plastic. The fiber provides strength and the plastic encapsulates the fibers, holds them together and distributes load between them [4]. The material is technically attractive because of its combination of high tensile strength and low weight [3]. Within traditional fiber composites research most attention goes to optimizing the mechanical properties, determined by a number of parameters such as raw materials and manufacturing processes. The typical applications for fiber composites are found in the transportation and wind turbine industries, where the necessity of light, strong and form-flexible materials helps to optimize the strength and shape in order to increase the efficiency of the systems. For these applications the composite construction is usually hidden beneath layers of pigmented coatings that smoothen the

surface in order to increase the resistance to the environment and to reduce the air resistance. The pigmented coating, however, hides the textile structures, which are believed to possess a strong visual potential.

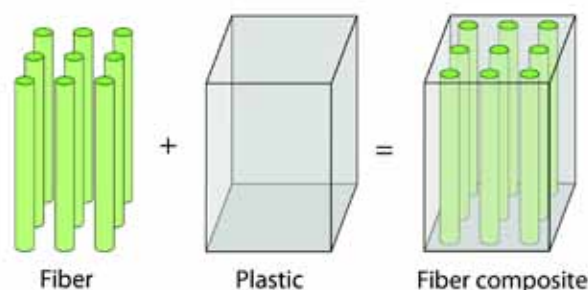


Figure 1: Schematic illustration of a fiber composite

Potentials in Architecture

In architecture there exist desire for building materials that enable organic and in general customized shapes with a unique expression. Façade modules in buildings, interior as well as exterior, are often attached to the building as an independent component, as shells, providing the wanted surface, and are thus subjected to no or limited bearing loads, which makes extraordinary mechanical properties unnecessary. Furthermore utilizing lighter building materials a lighter construction is necessary, which again saves materials and in the end money. With the concept of visual fiber composites the potential of adding an aesthetic value is emphasized.

Visual Fiber Composites

In a broad sense the vision of visual fiber composites is an attempt to create a mindset that recognizes the importance of the textile in fiber composites; making it the active component in the material while letting the plastic be a tool to encapsulate and protect the textiles from the surrounding environment. With this approach it should be possible to develop a multifaceted material that possesses strong textile associations such as comfort and coziness. It seeks to change the focus from wanting the strong material to wanting unique and attractive materials, with visual expressions and identities mainly defined by the textile contribution.

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When demonstrating the mindset it has been further emphasized to challenge the common practice of industrial production of fiber composites by discussing how the introduction of new materials and alternative production processes can generate a visual attractive material with a strong environmental-friendly profile.

The studies

The studies included in the article seek to strengthen the concept of visual fiber composites. Hence one study has investigated the integration of functional elements in thermoplastic fiber composites to show how this could broaden the technical use of fiber composites and thereby make it attractive for new users, whereas another study demonstrated the concept of aesthetic fiber composites, obtaining their visual identity from textile structures and treatment techniques. The purpose of this was also to explore, which textile techniques that could be translated successfully into this new context.

The two studies were closely related and the discussions, results and conclusion will be treated as a whole and help to establish a holistic understanding of the concept.

DEVELOPMENT OF AN ENVIRONMENTAL-FRIENDLY MATERIAL ALTERNATIVE

These days environmental-friendly sustainability is on everybody's lips. Continuous climate changes, pollution, increasing population and overconsumption of global resources are clear indications that it is necessary to find alternative solutions, if we want to maintain our living standards in the Western World.

Material development is fast and continuing and new materials are invented, developed and optimized concurrently with increasing demands from industries, where the materials are used. This means that materials to a greater extent are developed for a specific purpose.

The Environmental Impact of Fiber Composites

It can be argued that fiber composites strengthen environmental-friendly architecture because of the ability to minimize the consumption of raw materials and constructing materials specifically developed for the purpose. In some aspects this is true, but most fiber composites today made from non-renewable raw materials that are difficult to recycle [17]. In the fiber composites industry thermosetting plastics are common as resins, partly because of a low viscosity making them easier to process. Because of their irreversible nature, thermosetting fiber composites are difficult to recycle and are usually re-used as e.g. landfill or burned. Furthermore it has, so far, not been possible to manufacture a thermosetting resin that does not release styrene when curing [16].

Using a thermoplastic resin the manufacturing conditions change because of the different plastic behaviors. Thermoplastics possess some properties that are regarded as beneficial in this context and with the thermoplastic biopolymer PLA it is possible to manufacture a material from 100% renewable sources, that is recyclable and with an aesthetic strength that makes it an attractive alternative to

existing building materials. A beneficial behavioral property is e.g. post-shapability due to a reversible solidification process.

Visual fiber composites – a good alternative to textiles

With the recognition of the importance of having a good indoor climate, the conditions for using textiles in the interior space are damaged. People use more than 90% of their lives indoor and the effect on substances found in buildings environments with a bad indoor climate has health implications [7]. Textiles can provide good acoustic environments, but is problematic due their porosity that generates high levels of loose fiber particle in the air. In public institutions such as hospitals and day cares the use of textiles are phased out as a result of aggravated requirement for hygiene and need of maintenance. Visual fiber composites keep the expressions known from textiles, but the materials are non-porous. Additionally using environmental-friendly materials no substances and diffuse to the air and by designing a proper surface, the material can reject dirt, dust and bacteria.

Choice of Materials

The used materials have been chosen from the vision of an environmental-friendly fiber composites with properties enabling the functional and visual elements in the studies.

Why natural fibers?

The common fibers used in fiber composites are glass, carbon or aramide fibers. These have good tensile properties, important in the applications fiber composites are used for today [2]. Research in natural fibers is driven by the wish to reduce the synthetic fibers' negative effect on the environment [1]. For fiber reinforcement mainly plant of vegetable fibers are used, which are characterized with a lower weight and lower manufacturing costs. Generally their mechanical properties are good and with a lower density, their specific tensile properties are better than their synthetic counterparts [2]. The quality of the fiber composites depends on the distribution of the resin around the fibers and prevention of air cavities. The cellulosic composition of the natural fibers facilitate the absorption of resin in the fiber, but cellulose molecules are hydrophilic and hygroscopic, enabling them to absorb moisture, making them receptive to polluting substances [18].

In the studies mainly fabrics of cotton were examined. Even though cotton's tensile properties are less than e.g. ramie or flax, the fineness, uniformity can generate more delicate materials [8]. The studies focused on the fiber composites' visual expressions and the large selection of fabrics and available treatments for cotton made the natural fiber evident.

PLA – the plastic of the future?

Poly(lactid acid) (PLA) is an aliphatic polyester made of renewable sources such as starch and sugar, which is

fermented¹ by microorganisms in order to produce biologically degradable polymeric macromolecules. The polymer is based on lactic acid, which can occur in two different isomers, D(-)PLA, L(+)-PLA. Polymerizing the monomer can create polymers with same physical properties, but with alternating mechanical properties as the isomers-distribution determine the polymers ability to crystallize. High content of L(+)-PLA produces crystalline PLA, while polymers with higher content than 15% D(-) PLA is amorphous [13].

As a sustainable material PLA is explicit, as good mechanical properties is combined with biocompatibility and biological degradation. It is possible to adjust properties by morphology, crystallinity and co-polymerization making both glass-like and rubber-like polymers occur [1]. In many aspects PLA has similar properties as other polyesters such as polyethylene terephthalate (PET), polypropylene (PP) and polyethylene (PE), but compared to the conventional plastics that have been commercially available since the 50s-60s, PLA still needs extensive further development. Nonetheless it is possible to translate some of the processes such as injection molding and extrusion as long as it is possible to prevent chemical, thermal and mechanical degradation during the processes [1].

EXPERIMENTS

The manufactured fiber composite laminate consisted of alternating layers of textiles and PLA-sheets. The function of the textiles was to contribute to the overall visual impact, to enable a function or to provide strength and stability. The visual textile laminas were made of woven, knitted and non-woven fabrics mainly from natural fibers being dyed, printed and else wise treated in different manners, whereas the stabilizing textile laminas were made of a plain cotton weave.

The laminates were manufactured in an industrialized thermo consolidation device at the Fiber Laboratory, Department for Materials Research, Risø DTU National Laboratory for Sustainable Energy. The process conditions were set to heating the lay-up to 190°C for 5 min in vacuum followed by consolidation for 1 min under pressure.

The manufacturing device enabled laminates with the dimensions 40x40cm; large enough to give an indication of the workability of the given material combination, but too small to fully understand its visual strength.

Part 1 – Functional Fiber Composites

The work with functional fiber composites aimed to illustrate the potential in integrating selected functional elements, which was emphasized to be beneficial for both the material's visual and functional value. The elements were chosen from a reckoned potential in an architectural-

related context. After testing different elements, one was chosen for further development and put into a working concept.

Part 2 – Exploration of Textile Structures and Techniques

With the focus on using natural materials the textile design and technical inputs were also made with inspiration from nature. Based on the four elements *fire, air, earth and water* different textile designs were developed, combined and adapted to correspond with different textile structures and treatments in order to give a broad representation of materials.



Figure 2: Inspiration for the textile design with inputs from nature (photo: Louise Ravnløkke).

EXPERIMENTAL RESULTS

Part 1

Solar cells. Integrating solar cells would give a material able to generate energy from the sun. It would remind of the already-used glass/solar cell-material but be less sensitive than the fragile glass. The idea was good, but with the materials and processes used, the result was unsuccessful. The semi-crystalline solar cells used broke in the manufacturing process, possible due to the applied pressure and flow of the resin. Alternatives would be to use another solar cell such as amorphous solar cells, but their efficiency and service life are lower or manufacture the materials else wise.

Light-Emitting Diodes (LEDs). Integrating LEDs create a luminous material with appearance defined by the type, placement and control of the individual LED units. As for the solar cells the LEDs were also destroyed in the manufacturing caused by the combination of high temperature melting the diodes and the following pressure. The most apparent alternative would be to use a thermosetting resin and thereby also another process. Experiments carried out with this constellation were successful.



Figure 3: Representations of the preliminary experiments. From left: solar cells, thermochromic print, LEDs, phosphorescent print (photo: Karen Marie Hasling).

Phosphorescent print. Fiber composites with patterns in phosphorescent print give different visual appearance when it is dark. The intensity of light from the print was lower for

¹ Conversion of carbohydrates into alcohols or acids under anaerobic conditions.

textiles integrated in the fiber composite than for textiles themselves, but the function worked well.

Thermochromic print. Fiber composites with textile patterns in thermochromic print change when subjected to changing temperatures. In use the alternation could e.g. be caused by changing temperatures in the surrounding environment or by heating from an external or internal heating source. The integration proceeded without any problems.

In the continuous work thermochromic textile prints were combined with an internal heat source constructed of a conductive knit placed under the visual textile lamina in the fiber composite. This combination made the material fade in areas with the conductive knit, when an energy supply was put on. In the project hexagonal modules with different paths of conductive knit could be joined to create a large grid of slowly color-changing modules.

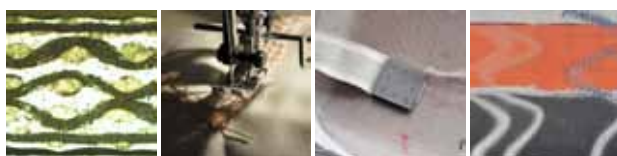


Figure 4: Representations of the final experiments with thermochromic print in a functional fiber composite. From left: The cross-section of the laminates, fastening the conductive knitted band to the textile, joint for connecting multiple modules, surface color change caused by internal heating (photo: Karen Marie Hasling).

Part 2

In general it was possible to manufacture fiber composite laminates with a strong visual appearance, where it was possible to maintain the visual textile contribution despite being integrated in a plastic matrix and being subjected to extensive heat and pressure during the manufacturing process. Furthermore it was shown that fine and delicate as well as coarse and irregular textile structures are suitable for this purpose and the spatial sense generated by the structure of the textiles and the composites lay-up is preserved.



Figure 5: Representation of identical patterns of burn-out in different materials (photo: Karen Marie Hasling).

Many interesting effects were observed that have helped to understand how textiles can be represented as part of a fiber composite, making it easier in the future to choose and

design materials and treatments and construct the right lay-up matching the desired outcome. Identical fabrics may appear differently with different background materials and different materials come out differently even with identical lay-up conditions; figure 6 shows good representations of this.

One of the main complexities was to predict the visual outcome of the lamination in advance, which appeared difficult as materials changed due to the temperature exposure, especially making the color of the textiles change. Furthermore some textiles were damaged by the heating due to thermal degradation of the materials, initiated by chemical degradations when treating the textiles. In figure 6 (left) a before and after picture of a laminate with a top layer of burn-out rayon is shown. The chemicals used in the burn-out treatment have damaged the fibers in the surrounding areas of the burn-out causing them to thermally degrade in the manufacturing process. In figure 6 (right) a before and after picture including a non-woven polyester layer is shown. Due to the lower melting temperature of the non-woven this has melted in the manufacturing causing the printed dye to flow out and mix into the PLA-matrix.



Figure 6: Adaption of expression from diffuse and flexible fabric (left) to integrated and rigid fabric appearance (right) (photo: Louise Ravnløkke).

MATERIAL PROPERTIES

Contributions of Fiber and Plastic

The fiber and the resin have different contributions to the overall material properties. Fibers are stronger than their plastic counterpart and will be determining the mechanical properties of the fiber composite. This even though the fiber volume fraction is usually lower than the matrix volume fraction. Unless post-treating the material only matrix will be present at the surface, making the material properties for the matrix responsible for environmental influences on the surface, such as chemical degradation, UV-degradation or bacterial degradation. Both the fiber and the plastic can influence the visual properties.

Mechanical properties

Tensile strength	Fiber
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Technical properties

Chemical degradation	Plastic
UV-degradation*	Plastic
Bacterial degradation	Plastic
Burning properties	Plastic (& fiber)
Hygiene	Plastic

Visual properties

Surface structure	Plastic
Integrated structure	Fiber
Colors and light diffusion	Fiber (& plastic)

Table 1: Overview of fiber and matrix contributions to the material properties (No literature on how fibers covered with plastic are influenced by UV has been found).*

In this study the mechanical properties have been neglected and it can be argued that the plastic is responsible for the technical properties whereas the main contribution of the fibers is to the visual outcome.

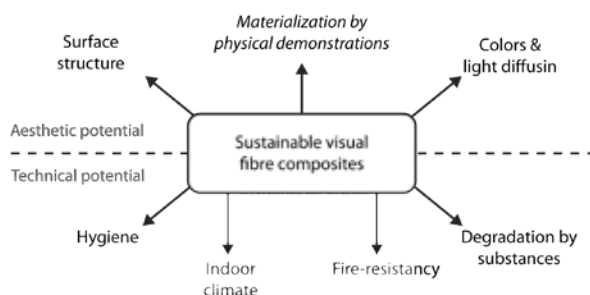


Figure 7: Dimensions of material properties.

Technical Properties

PLA is an emerging polymer and the behavior of fiber composites is non-linear. Therefore it can be difficult to translate results between different environments and situations.

Surface degradation

As PLA is composed of natural existing units it can be degraded by organisms, e.g. in the human body. It is a furthermore a polyester and will as other polyesters be degraded under certain conditions. Polyesters degraded in water, but the degradation rate is low and has limited practical importance. Under alkaline conditions ($\text{pH} > 7$) the polymer degrade by hydrolysis, resulting in changing material surface character and corrosion [5, 9]. The visual appearance in will change, as this will cause color changes and surface textures.

Preventing thermal degradation

An untreated fiber composite consisting of a natural fiber and PLA would not pass a fire-test, which is necessary to make the material commercially accepted. Fiber composites can be fire-retarded by using a barrier, fire-retarding the fiber or fire-retarding the resin. In this case a barrier would impact the visual appearance of the material, which is undesired. Impregnating natural fibers with fire-retardant chemicals would influence the interfacial between the fiber and resin affecting both mechanical and visual properties. Moreover mainly the resin will be subjected to the fire source and the voluminous amount of fibers is lower than of resin.

By time it might be possible to co-polymerize fire-retarding molecules with PLA, as it is the case for the commercially available polyester Trevira CS [11]. This is advantageous

because the fire-retardant is integrated in the polymer, which means that the effect will not decrease with use or cleaning [6]. Until then the fire-retardant chemicals have to be added to the polymer melt.

A considered part of the fire-retardants formerly used are strongly carcinogenic, but was convenient because they could be added directly to the melt [10, 12]. The availability of environmental-friendly fire-retardants is still limited. Apyrum from the company Deflammo AB consists of inorganic phosphorous salts. In aqueous solutions the chemical can impregnate e.g. textiles and paper, but in powder form the chemical could potentially be added to a melt [14]. Fire-retardants from organic compounds such as lignin and starch in an intumescent fire-retardant is studies by Reti et al. [15]. The results have been satisfying, but as lignin and starch are yellow-brown this will affect the appearance of the material.

COOPERATING ACROSS TRADITIONAL DISCIPLINES

An aspect of the studies has been to investigate how the different actors involved in the processes have worked together and realized the concept and its practice. The textile designs were made by two textile design students from Kolding School of Design without any previous experiences working with fiber composites. With their focus on the textile component only they designed designs and used technologies that challenged the further fiber composites manufacturing, especially by means of spatiality and temperature-caused material changes. In some cases this destroyed the expected visual expression but in other and often occurring cases, the materials got even more interesting and extraordinary.

Textile students are trained to understand and use textiles in contexts where textiles are commonly used. Being involved in the design process of the textiles and the fiber composites, the understanding on the technical properties of textiles improved and the importance of how the properties considered in the design process was emphasized. It can help the students to think out of the box and to explore other and untraditional uses of materials; textiles as well as any other material used in product development and architecture.

CONCLUSION

The studies have shown that it is possible to make aesthetically appealing bio-composites that add a visual or functional value to the material that makes it attractive for new markets such as architecture and the building industry. As it has shown possible to utilize well-known textile techniques to obtain this value addition, the question is how these techniques can be optimized in order to get the best results? It requires both knowledge and experience with textiles as well as fiber composites to fully understand and predict the future aspects of the material. The studies have successfully aimed to illustrate potentials of visual fiber composites, but the result only generates a fragment of the essential knowledge of the potentials of the physical

material as well as for the market the material is believed to be perfect for.

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BioLace, an Exploration of the Potential of Synthetic Biology for Future Textiles

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ABSTRACT

Could 'living technologies' such as synthetic biology lead to a more resilient future? This paper presents 'BioLace', a speculative design-led research project that investigates the intersection of synthetic biology and textile design to propose future fabrication processes for textile products and architecture. The motivation behind this research lies in the hypothesis that living technologies can foster a new approach to address key sustainable challenges of the 21st century.

The BioLace project is designed to probe the potential of a biological manufacturing future by exploring the cellular programming of morphogenesis in plant systems. The project aims at translating synthetic biology into accessible design scenarios to expose and understand the societal implications of new emerging living technologies. The BioLace project poses the following questions: Can synthetic biology become a potential sustainable technology for future textile manufacturing? Will crafting molecules become a new way to produce textiles? Could biology combined with nanotechnology enable us to engineer intelligence in materials to program smart and responsive biological textiles?

Keywords

Synthetic Biology, Living Technologies, Morphogenesis, Bio-fabrication, Plant Architecture, Smart Textiles, Intelligent Systems, Lace, Programmable Molecules, Self-Assembly, Bottom Up Processes, Sustainable Design, Textile Architecture, Resilience.

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Neocraft: Exploring Smart Textiles in the Light of Traditional Textile Crafts

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ABSTRACT

Smart and interactive textiles have resulted from exploration and adoption of new materials and technology of the Digital age and can be described as the next phase in the evolution of Textiles. As we learn to make textiles with new properties, it is important that we also define the narrative of smart textiles. To develop narratives for smart textiles we can learn from the traditional textile craft communities who, for generations, have successfully embedded their cultural narratives within their fabric, creating textiles that are functional as well as coded with meaning and purpose. This paper describes ways in which craftsman understood and explored materials; the need for us to be craftsman and explore materials that can create new narrative and myths; it also highlights the need to involve traditional artisans to be part of the smart textiles exploration and to learn from them to create transient textiles that can lead to new interactions and experiences.

Keywords

Traditional textiles, Craft, Smart textiles, NeoCraft, Digital technology, Democratising technology

INTRODUCTION

Recent years of research in the field of smart textiles has begun to redefine the function, meaning and language of textiles as we know it. Whenever there has been a new wave in technology, we have also seen a new wave in the evolution of Textiles. The two have been closely connected, each pushing the boundary of the other. At the dawn of the Digital revolution, we began to see the Textile industry quickly adopting and exploring new materials and technology that was now available.

At present we are in a transitional phase, trying to understand and create a new vocabulary for smart textiles. As we explore new materials and create fabric that are dynamic, responsive and smart, it is important to also reflect on the larger picture of what we are creating and why. How do these new properties change the meaning of

textiles? Are textiles becoming the new gadgets? Are we able to create new value and meaning with these new possibilities and fulfill a void that products of the industrial society have so far failed to fill? We are surrounded by products but most of these have been unsuccessful in satisfying a deeper longing that humans have. Gianfranco Zaccai states:

“the exact nature of the missing ingredients is difficult to define. This absence is perceptible, however, in the fact that most of these objects (industrial products) are not sufficiently satisfying to either our souls or our senses”[17].

So what kinds of artefacts or products satisfy our soul and our senses? What is the essence of such an artefact?

ESSENCE OF TEXTILES

The ‘essence of an artifact’ mentioned above can seem a bit abstract and intangible, but if we look at traditional craft artefacts, it is clear that these products fulfilled something more in our lives than our present day gadgets and products. To better understand gadget and craft objects, one can refer to the work of Wallace who differentiates between Gadget and Non Gadgets as shown in Fig 1 [15]. Here one can see the qualities of the Non gadget as being those also associated with craft artefacts.

Gadget	Non gadget
Short life span	Enduring lifespan
Transferable significance	Non transferable significance
Personal attachment based on function	Personal attachment based on personal significance
Object represents elements of consumer identity	Object represents elements of individual's identity

Fig 1. Gadgets and Non gadgets

Non gadgets or Craft objects creates a personal attachment that is based on personal significance. One would keep a pocket watch given to them by a family member (even if it did not tell time anymore) because the watch has memories attached to it and this significance cannot be transferred to

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another watch. There is a personal memory or significance attached to the object that makes it valuable to us. Craft and its associations with memories (or significance) can be seen as the result of the relationship of the craft process and time, as well as the use of the artefact over time. In his book *Slowness*, Kundera very profoundly points out the simple but direct relationship between speed and memory:

"There is a secret bond between slowness and memory, between speed and forgetting. Consider this utterly commonplace situation: a man is walking down the street. At a certain moment, he tries to recall something, but the recollection escapes him. Automatically, he slows down. Meanwhile, a person who wants to forget a disagreeable incident he has just lived through starts unconsciously to speed up his pace, as if he were trying to distance himself from a thing still too close to him in time.

In existential mathematics, that experience takes the form of two basic equations: the degree of slowness is directly proportional to the intensity of memory; the degree of speed is directly proportional to the intensity of forgetting" [9].

The traditional textile craft processes are known for its slow and lengthy processes be it spinning, weaving, knitting or printing. Craftsmen spend long hours in their studio and workshops preparing materials and applying various techniques to produce fabric. Repetition of patterns and rhythms in making were an integral part of the process. The focus was on the making and through this making one gained knowledge and understanding of the particular material and its possibilities. Once the textiles was bought and used, over time the user ingrains memories and stories in the fabric and even when the fabric is not of any functional use, it is sometimes kept safely for the memories it holds. In contrast to this when we buy textiles from the high street shops, we know that these mass produced garments were each made within minutes - each identical to the next. These clothes serve a much shorter lifespan, we are more quick to discard these clothes as we are subconsciously aware of the speed at which these garments were produced and how quickly they go in and out of style. The sheer volumes that factories produce has numbed us to very object we hold in our hands [13]. These clothes gain significance from fashion trends, and the speed at which market trends change does not allow us enough time to create personal significance. As new trends are set, the significance of the old are lost or easily transferred to the new, which once again only lasts for a season.

Craft calls for time to slow down and when time slows down, according to Kundera, we are able to remember better, we are able to create memories and value. Memories give us our identity and context in society, it creates for us the narrative within which we live. Time also weaves in myths and narratives in traditional textiles and gives the wearer their identity and context in society.

Traditional textiles have served a myriad of roles. It performed functional roles as well as religious, political, cultural and mythical ones. M.K. Gandhi created the

narrative of self reliance through textiles, where handspun and woven textiles served the concept of democracy [7]. Textile is believed to have magical powers that can transcend the physical world and affect the spiritual realm, it can protect, bless, guard and guide. Research has shown that textile and embellishment worn in the physical world often acted as a bridge to the spiritual world [12]. Pabuji Ka Phad is a painted textiles that tells the story of Pabuji, whom the Rabaris of Rajasthan believed was a hero and god. The textiles not only told the story of Pabhuji, it contained the deity himself. The painting was completed with the last act of drawing in the eyes of the Pabhuji, and this was a ceremony that welcomed the deity to reside in the textiles, from then on the textiles was considered sacred - the painted textiles was now an alter; at the end of its life it was immersed in water, releasing the god from the fabric. In Thailand and Laos, consecrated shirts painted with Buddhist religious designs, was believed to make the body invincible, so warriors wore these garments to make themselves bullet-proof [12]. Numerous such examples can be seen in traditional textiles across cultures. Textiles were also deeply coded to communicate identity and one's context in society. The Rabari community in Western India wear extensively embroidered clothes and veils. The embroidery was a coded language people knew how to read, the colours and patterns would reveal ones social status, their trade, if a woman was married, had a son or was a widow. Textiles was considered powerful, spiritual, protective, beautiful and it reflected the hopes, beliefs and identity of a culture.

It is this intangible essence of traditional textiles, the narrative it carried, that made it such an integral part of culture and community – it enabled one to transition through the multiple narratives of society. These narratives and myths embedded in craft artefacts were part of a collective mythology that the community lived by [2, 5]. When the world outside – economy, technology, environment etc. was changing, the anchor for a community was in the myths they believed. These were embedded in their fabrics to carry them through the worldly shifts [2, 6]. Craft served a far deeper purpose than functional and decorative, the essence of these textiles was its ability to not be bound by time and space, it enabled the creation of memories, gave identity and context. It allowed room for transitions and change and were anchors in a shifting landscape. The ability to transcend the physical through myths and the slowness in the making and use of craft artefacts could be some of the missing ingredients that our soul and senses are longing for.

It is important to note here that the past is not being romanticised or that one is not claiming that we go back to the dark ages. Society has advanced in many ways and technology (bringing with it speed) has enabled many positive and needed change to our lives. What we need are tools and artefacts that help us to find a balance when the changes are happening too fast.

There are three Japanese words here to help us understand the idea of 'transition'. In Japanese, *Utsutsu* is the word for

reality, Utsu is the term for dream and then there is a third term for the transition between these two states which is Utsuroi. This word means changing, transient, fading and shifting. Utsuroi enables us to transition, or fade from one state to the other. Torii gates and bridges are considered paths of transition or shift. Torii gates are found at Shinto temples in Japan. Walking through these arches that start at the entrance and leading to the shrine symbolizes the Utsuroi or transition of a person from his/her everyday life to the spiritual, from the impure to the sacred and pure.

If we can grasp this concept which allows us to oscillate between the real and dreamt, tangible and intangible, the physical and spiritual, it could be a concept we adopt to create narratives and meaningful relationships between the users and artefacts and can guide us in the kind of artefacts we make as we define the future of smart textiles.

Chandavakar highlights the work of Michael Goldhaber who stated that we live in an "attention economy". We are overwhelmed with information and all the information is calling for our attention, this makes attention the most scarce resource [4]. Craft calls for two of the scarcest resources of our society - time and attention. When we interact with craft artefact we are aware of this and value craft highly because the product is a result of resources that we highly value and wish we had more of. Smart textiles craft can help us to reflect on our times, to create new narratives and myths that allow us to shift between the ever increasing changes in our lives due to the influx of information and the increase in speed. Smart textiles, by allowing us to create memories, can help slow down time for us.

NEOCRAFT - CRAFTING SMART TEXTILES

Smart textiles is still at its infancy and we have the privilege and responsibility to decide what the purpose and role of smart textiles can be. As designers and researchers, our core mission has been to identify and fulfill the needs of our society. We have recognised the need for products that satisfy the soul and senses. We have also identified craft artefacts as being successful in satisfying us in this way. Craft requires time to slow down and helps us to create memory and value. Its material and physical qualities satisfied the senses. Traditional textile crafts have served multiple roles in society including being a medium to connect with the immaterial and spiritual - this satisfied the needs of the soul. We have also seen the need for creating narratives; myths and slowness have been identified as key elements in our use and engagement with artefacts. It is necessary that we integrate these ideas into our practice to create artefacts that sit in the gap between gadget and craft. I have referred to this new group of artefacts as NeoCrafts [14], a new kind of craft that results in creating products that enable us to create memories and personal significance, thus allowing us to reflect and create our identity and place in society. These artefacts are also tools that will allow us to better transition between the material and immaterial.

In this context, we can now define a direction for the craft of Smart textiles. Over the last decade, like children with a lego set, we have been building, breaking, making and

exploring the possibilities of a new genre of textiles - Smart and Interactive textiles. Having recognised the value and essence of traditional textiles, contemporary craftsmen and women can learn and borrow from existing knowledge about making found in craft communities to create NeoCrafts.

“Craft presents us with the oldest knowledge there is: the most fluid knowledge our culture has produced – knowledge about making things” [11].

Since the craft of Smart Textiles is still young, we can draw from this 'fluid knowledge' that exists in the traditions of textile crafts. In our pursuit to create a new world with possibilities that technology and smart materials has offered us today, we can learn from the creative processes of the traditional artisans.

The challenge faced by society today, according to Sennett, is knowing how to think like a craftsman while making good use of technology [13]. The process of knowing through making is an integral way of thinking for a craftsman. It is his/her material consciousness, curiosity of the material in their hands, that motivates them to create something original [13]. Smart textiles is at this stage where we are curious about new materials (information technology, electronics, smart materials). We are making and learning with materials that previously was not part of the textiles discipline and vocabulary. New materials brings with it new challenges and possibilities that have caught our imagination.

The majority of work seen in the field of smart textiles has been mainly in the realm of early material exploration and prototyping. These explorations have been important and necessary but the time has come to push past the gimmicks of new materials to really constructing meaning and narratives through these new textiles, and to develop smart textiles into a craft in its own right. During this process of making, we need to be humble and accept that we do not entirely understand what we are making [13]. As Heidegger says, the meaning of what we have made can only be gleaned through its use, by using it we begin to understand it. Although we might not always know what we are making, it is necessary that we still make them so that it can be used and it is in the use that we can gather new knowledge about what to make. Numerous smart textiles prototype examples have remained as prototype and has not moved to products that can be used and tested. Part of the reason for this has been because the field is still young and it is difficult to find an environment where all the elements are available to turn a prototype into a product, limitations in technology also makes this translation difficult. Nonetheless, we still need to push our work beyond prototypes and test of ideas. Until we have smart textiles in our homes and work spaces, we will never fully understand what they are and how we will use them. Adrian Forty points out that products often go through different phases during its aesthetical evolution. First the products are technical solutions to a problem, then these solutions are hidden in familiar objects (making it easier for users to accept the new solution) and finally the product finds its

own form and function in the home [3]. I would like to stretch Forty's idea of aesthetic evolution of products to see the change thermochromic inks have gone through since its development. Thermochromic inks were developed in the 1970s, these inks temporarily lose colour when exposed to heat. This technical solution soon moved to the next phase in its evolution to become hidden in familiar objects around us like the mood rings and t-shirts that were popular in the 80s. It was also integrated into thermometers and coffee mugs for advertisements. The works of Linda Worbin has moved the material into its third phase where she has extensively researched on thermochromic inks for Dynamic textile patterns. The work explores hidden patterns in textiles, where patterns are revealed when it is used; the ability to get precise and controlled pattern changes such as stripes to checks using heat as a material (something textile designers never had to think about before); pattern repeats are rethought as static print design has become dynamic and offers infinite expressions [16]. This body of work is an example of how thermochromic inks is moving into its final phase where it is trying to find its own form and function. Here the material was explored not only for its colour changing properties but it raised questions about how designers design textiles that will continuously change with use. Time and information technology are new materials to be explored by textiles makers, these materials are changing the way we make textiles as well as how we use them. Worbin's work is an example of pushing past the initial excitement of new materials to really engaging with it in a deeper way, to understand the inherent potential of the materials and in the process moving smart textiles to a craft form.

One can relook at the Bauhaus process to understand better what is required of us today. Anni Albers left for us an extensive collection of work where we can see her experimentation with composition, colours, construction and materials through weaving and other techniques. The Bauhaus called for a time of deep exploration of materials, it was a personal and intimate exploration of materials. They gave little attention to what the material was previously used for, its practical application, instead they deepened their techniques and played freely with materials, this resulted in a new style [1]. Smart textiles is a young field and there is still very little knowledge and expertise available. As we build the foundation of this field, we need to be thorough in our study of these materials, turning into craftsman who engage with materials in an intimate way, to produce new knowledge and skills that will mature the field.

The intent of new technology we create should not be to replace existing activities such as craft, this is what technology built during the industrial revolution aimed for, but it should complement and enhance existing activities [10]. Smart textiles again gives us the opportunity to rediscover crafts and its new role in contemporary society. For this we need to also invite existing craft communities, often in the margin of textile communities, to be part of this process. We need to create opportunities for more artisans to engage with new materials and technology. There needs

to be a democratisation of technology that will enhance craft activities and enable the Crafts to evolve and artisans to sustain themselves. We need to create an environment that encourages and enables the bi-directional sharing of skill and knowledge.

CONCLUSION

Chandavakar said:

“Craft objects originally were objects of use as well of contemplation...the thinking and making of an object was always interlinked... Craft really is a rooted tradition – it is a process by which a community reflects on its condition – this sort of reflection is actually a search for identity” (as cited in Kasturi, P.) [8].

Smart textiles has the ingredients and potential to be far more than functional fabrics as examples in the field show us. By exploring smart textiles in the light of traditional textiles we can regain the essence of textiles. This can be done by developing smart textiles into a craft in its own right, producing work that calls for deeper skill and knowledge that enables one to create memories, meaning and value as well as be a tool that allows one to oscillate between the states that our society and self demands of us. We can do this in collaboration with traditional artisans, each sharing their body of collective tacit knowledge and sensibility. Smart textiles artefacts should enable us to transition between the fast and slow, physical and virtual, intellectual, spiritual, material and immaterial - satisfying both our soul and senses. It should facilitate the creation of meanings and memories through the symbiosis of traditional craft knowledge, craftsmanship and new technology. The result of this explorations can define the future of textiles, its meanings and language, and be a medium that enable Utsuroi, or transition between the ever increasing changes of our textile, technological, social and cultural landscapes.

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Reflections on a Craft Design Protocol

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ABSTRACT

For some years I have been working on a design protocol of craft, which aims to unearth the working principles of one cultural area (contemporary craft) of production for the benefit of another (interaction design). The methodology that led to its formulation comprised my research as a doctoral student in Interaction Design, and made up the bulk of my thesis [22]. The protocol has recently been more fully explored for the craft community, with each tenet explored in more depth [24]; however, several important publications and conferences in the field have emerged since its initial formulation and if it is to have any relevance, the protocol needs to be revisited in light of them. These include Sennett's *The Craftsman* [36], Risatti's *Theory of Craft* [34], and Adamson's *Thinking Through Craft* [1]. In addition conferences such as Neocraft [3], and collections of writings such as Extra/Ordinary [5], which includes Mazanti's SuperObjects model of craft [28], have developed the field immensely. This paper critically reflects on the protocol in this new expanded context.

Keywords

Craft, design methodology

STRUCTURE OF THE PAPER

The paper begins with a short summary of the seven tenets that make up the protocol, an explanation of how it came about through a period of research, and its position within a larger methodological framework. Subsequent sections use each tenet to examine its place in the expanding field of discourse around craft; some space is then given over to a description of how a recent interdisciplinary research project has been informed by the broader craft research methodology; the concluding discussion reflects on the major issues of concern shared by this protocol and current craft theory, and delineates where there are still important differences to be explored.

THE PROTOCOL IN BRIEF – WHY AND WHERE IT CAME FROM

Hallnas and Redstrom have pointed out that if the fundamentals of design are changed then very soon it can no longer be considered design. However, both design and art have been conducting a love affair with craft for some time now, borrowing tropes and signifiers of timescale and commitment in an effort to get closer to 'real' life, to work with concepts of authenticity [23, 28]. This protocol formed part of a larger enquiry into what craft might bring to Interaction Design; in addressing this core aim of the research it was necessary to be able to explain what craft was to other disciplines, and to move if possible beyond the temptation in technologically oriented practices to use craft merely as a prop supporting romantic tales of tradition, or in creating spectacular futures [26]. Instead the goal was to reinstate the object as a thing open to human systems of meaning making in the here and now as in Ingold's conception of a 'world without objects' [19, 20]. The specific domain I was working in was wearable computing, where the dominance of the 'borg' was at the time being newly challenged by practices and aesthetics more usually found in domestic crafts. Researchers in such as Maggie Orth [32] would include in their reflections on design process accounts of being instructed in the (feminine) traditional skills of embroidery and crochet by grandmothers, for example, a narrative visibly

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at odds with the post-humanism of the instrumental engineering approach. My experience as a jeweler and contemporary craft gallery manager suggested there was more to craft than this, that there was something more fundamental at work, which might benefit the evolving fields of wearables, interaction design and physical computing. Was it possible to define what that was, and how could it be made available to these other disciplines?

The protocol was one part of a longer four-year program of reflexive research into practice. It was initially informed by an exploratory piece of product design, which aimed to use craft explicitly to engender feelings of familiarity [25], and by interviews with post-graduate level jewellery students and transcripts of talks by internationally recognised jewellers. This primary research, coupled with an ongoing literature review, began to reveal issues of authenticity as design attempts to borrow from craft, and this was subsequently explored fully through a literature review of the evolution of authenticity as a cultural phenomenon [22]. The argument for craft as a site of authenticity followed, citing the ambiguous conceptualizations of the field as proposed by White [39] and Mazanti [26] in relation to calls in the interaction design literature for new approaches to design metaphorical presence beyond use-value [14] and availability of the technological object for critical reflection [4].

At the time, to talk explicitly about craft process was still contentious, and theorists were being careful to defend their work against those who believed such enquiry only serves to destroy the ‘magic’ and romance of craft. To present a protocol suggesting craft might be available to other creative worlds felt something like an act of betrayal. However, over the past few years, the domain of craft theory has expanded dramatically and is gaining credibility with those who make as opposed to write. The conditions presented in the protocol may not all be necessary for craft to exist, nor might they be sufficient, and this paper begins to examine how developments in craft theory challenge, extend or reaffirm them.

THE PROTOCOL: CONDITIONS FOR CRAFT

The conditions are listed here in their original form to give the reader an overview of the protocol. For fuller descriptions the reader is directed to [24, 22].

One :: risk and visual language

the risky non-predetermined process results in original visual language, seen to embody particular political and metaphorical values

Two :: extending material

‘material’ may include traditional materials, technologies, processes and methods, each having their own affordances and constraints

Three :: internalisation and visual language

internalization of material – both source material and the material being worked – is essential for the development of original visual language

Four :: processes of internalisation

this internalization is achieved through action – techniques include drawing, direct manipulation of material, and repeated exposure to the material

Five :: embodied process

control over formal expressive elements at diverse effective ranges is dependent on an embodied understanding of the process of production

Six :: signifiers and authenticity

signifiers of craft are not to be confused with the original visual language which emerges only from the internalization of material

Seven :: undecidability

craft practice, objects and consumption are characterised by an undecidability of purpose and cultural placement. As such, they are unfixed and occupy a unique space between art and life.

The following section brings together some of the broad themes that characterize current craft theory, and discusses these conditions in relation to them.

THEMES IN THE CRAFT LITERATURE

The broad themes discussed here are: networks of production; the sociological dimensions of craft; material consciousness; and material culture. These are arranged in pairs, corresponding first to process, and second to outcome.

Networks of production

Accounts of shared production featuring craftsmanship have focused on the apparent sleight of hand being performed (taking credit for a piece made by someone else) or the reinforcement of the hierarchical cultural struggle between art, craft and design: as artist Jorge Prado says, “I don’t think that art gets made with your hands” [33:15]. We may find that some working relationships are easier to accept than others – Marc Newson trained as a jeweler, and operates as a designer – and even for a jeweler, it is normal practice to employ a specialist to set thousands of sapphires and diamonds as in the case of Newson’s *Julia Necklace* [33]. I have used the word craftsmanship deliberately here, as it is generally skills that are being described in the service of some higher vision. However, it is true also to say that much craft is practiced as a shared endeavour, with many specialists completing different aspects of a larger job. Oppi Untracht’s introduction to his seminal teaching text, *Jewelry, Concepts and Technology*, includes a diagram of related outlooks, specialisms and materials in the field of jewellery and silversmithing [38]. In naming this diagram a *convocation* rather than a map, Untracht was seeking to draw attention to the fact that everyone was welcome and had much to learn from each other. When art or design

approaches craft in this way, we do find cases of practice that make more sense to us: Fred Wilson values the connection that a craftsman can bring to the fabrication of an artwork, and the “wonderful relationship” that can develop with the artist [33:29].

Sociologists such as Bruno Latour have sought to show that in fact all production is social, and Hutchins goes so far as to claim that cognition itself is distributed, based on studies of navigation on board US navy ships and scientists discussing chemical reactions [17, 18]. Now David Gauntlett is bringing together theories of social capital with creativity to argue that shared creative production can only be a positive force for all of us [12].

Craft has provided the case studies and served as a model for growth and learning in the development of influential pedagogical (and management) theories of communities-of-practice [27], a model which in turn becomes embedded in the pedagogy of craft and design disciplines [11]. Of disciplines themselves, it is becoming harder to draw boundaries as the range of materials available to the maker increases through the efforts of materials science, and indeed, as we extend what we mean by ‘material’ itself. The democratic, convivial character of open source and hacker communities is becoming a part of craft not only as it develops its own overtly political practices in craftivism, but as it engages with new technologies and draws on the expertise of others to serve it in turn. Programming and hardware become material just as much as wood or silver or cloth, and may require that the craftsman collaborate or outsource to achieve something more than a record of their struggle with the constraints and opportunities of a new process – just as we might not be able to set our own sapphires, so might we not be able to program our own interactive jewellery [40]. Recent research workshops in the domain of design examine the range of such collaborations in a way that craft and even art literature often do not, reflecting on inter, multi and trans- disciplinarity as social models of knowledge underpinning the new design consultancies [35]. These are mature reflections on authorship and ownership without the anxiety that can still pervade craft discourse. Grace Cochrane’s discussion of Australian and New Zealander makers working across craft and design is an excellent exception [7], and challenges one of the outcomes of the protocol presented here – that is, that the visible authorship of the maker is still important. Instead Cochrane cites makers who find that craft (the control of a process of production from start to finish) and craftsmanship (skill with a particular material) are bound up in many different ways with scalable, sustainable production. It is this first dimension that the protocol misses, and my assumptions about ‘fine craft’ as the focus of the research at the time are clearly revealed.

The sociological dimension

Adamson cites Bourriaud’s relational aesthetics and the shift from studio to site as recent functions of the move away from an individualistic modernism in craft [1:165], and points out how site at least conflates the spaces of

production and consumption. Such leveling can also be found in current thinking in sociology and in philosophy – objects and people, ideas and institutions, tools and media, are seen as potentially having equal importance.

In Interaction Design, the dominant model of engagement with technology as inherited from HCI was initially a one-to-one (person to machine) relationship. This has quickly been replaced as technologies become increasingly, explicitly distributed. My own attempts to bring craft and technology together began with a hardware/software hybrid whose creators saw it as the generic platform for Ubiquitous Computing – computing embedded in everything (a paradigm which grows apace, and which includes the concept of the Internet of Things for example). This networked technology, and a research question focused on how people make sense of novel things, led to my concentrating on the ways jewellery acts as a shared form of social expression rather than on aspects of intimacy or memory. In developing the craft design protocol and examining authenticity, there was a clear relationship between how authenticity has been understood at any given time in history, and how the individual has been seen as a part of society. That is, craft’s authenticity today includes a social dimension whereas the modernist form of authenticity has depended on the heroic individual, the lone genius who does not have to work through those tedious 10,000 hours to achieve mastery, but is instead inspired, or enlightened. Again, the protocol has not addressed the social reception of craft; rather, the jewellery made as part of the larger research methodology was wirelessly (and aesthetically) networked to reflect the social and cultural world of a particular female friendship group [22].

Material consciousness

If the protocol ignored the social aspects of craft, it emphasized the maker’s engagement with material as an end in itself. Responses in the interviews describing how some makers ‘operate within the matter itself’ [6:130] are echoed by Cochrane’s findings demonstrating the importance of drawing and scribbling, of face to face communication and of developing responses to material: material experiences lie behind creative processes [7:71]. The makers working with industrial methods she cites in NeoCraft echo Pye’s analysis of scales of engagement (diverse effective ranges) with objects and surfaces, and the corresponding need to be in contact with the different processes of production: Cochrane quotes flatware designer Oliver Smith as saying he learns, checks results and better understands each process with each visit to the ceramic casters he works with [7].

Sociologist and anthropologist Tim Ingold says that “the intentionality of skilled practice inheres in the action itself in its qualities of attentiveness and response whether or not any prior intentions are affixed to it” [20]. It is this processual design that craft celebrates and seeks to make evident through its objects. The extension of material to include new technologies, computation or the social world, does not change this conversational model, nor

does the wide range of tools at our disposal. Recent observational research shows that the craftsperson is fully cognizant when the whole environment (workshop) can be brought into play in conversation with a material through a kind of choreography [15, 21], a complex “prosthetic outgrowth” [20] in a performance of distributed cognition.

Art and design have pursued Ingold’s hylomorphic model of separation of matter (nature) and form (culture) in their own ways, attributing higher cultural value to the concept and the geometric plan. Craft in the meantime has sought to articulate what Ingold is suggesting here – that deliberate and highly skilled activity is not dependant on prior intention, but on an engagement with material that is more akin to language [20].

Material culture

Sennett’s writing on changes in pottery production suggests how material consciousness in the form of embodied practice becomes material culture, pointing out that changes in decoration as a result of new slip techniques could have economic value. He too holds that the “craftsman, engaged in a continual dialogue with materials, does not suffer” the divide between understanding and action [36:125]. This bridge between the experience of the maker and the cultural narratives of the object is interesting not only for material culture but also for our discussions of creative disciplines, as the aesthetic results of such engagement with matter very often come to signify identifiable communities of expertise. New materials such as precious metal clay (PMC) can reveal this anew as makers work through the techniques to work with and against the properties of the material, and new criteria for successful work emerge in the process. PMC has for example made very visible the debate around amateurism in metal working and jewellery in particular, with a large amount of work taking advantage of the clay’s impressionability – for a ‘fine craft’ audience, these works typically do not demonstrate the skills in finishing which have grown out of an engagement with metals in a different type form. Work that balances an engagement with PMC’s inherent malleability with traditional control of finishes in metalsmithing is more readily accepted.

Adamson’s introduction to the *Craft In Action* section of his 2010 edited volume contains a shock – he suggests that anthropologists often look to artisanal products to understand the everyday life of a culture [2:457]. He is right, but think for moment of the craft objects in your own home – not many of them, and not many of those are for use alone, but may play a role as ‘fine craft’ displayed for status and contemplation. Tanya Harrod writes of “house trained art objects” [16], reminding us of the alternative history in which real life has a tendency to muddle the neat divisions of art object and craft. In a review of *NeoCraft*, a lack of research “considering the role and significance of craft activity to consumers or to patterns of consumption” is noted [29], and I agree that there is a wider paucity of this kind of work. However,

theoretical advances are being made in particular by Louise Mazanti, whose recent writing (or original theories recently available to English readers) shows craft sitting astride the rarefied world of art and everyday life with reference to aesthetic theory and material culture [28]. Accounts of ownership and attachment can be found in the ethnographically informed research of the likes of Daniel Miller [31], and before him, Mihalyi Csikszentmihalyi and Rochberg-Halton [10], and Alison Clarke brings together writing on design and anthropology, looking both at how design employs observational techniques in user research, and at how designed objects fare once in the domestic sphere [8].

The seventh condition of the craft design protocol stated that craft practice, objects and consumption are characterized by an undecideability of purpose and cultural placement. This referenced Mazanti’s theory of the super-object, and attempted to extend it beyond the frame of material culture to include practices and experiences of use and consumption. In studying how the friendship group constructed meanings around my networked jewellery, I found that crafted technological objects were configured by the women variously as proximity devices, a system for personal expression on the body, and autonomous craft objects. More importantly, these configurations were dynamic and shifted according to the tenor of the ‘conversational floor’ (a democratic style of conversation apparent in female communication according to Coates [9]). This may have been due to the objects being unfamiliar (although the women had been party to designs and concepts over two years), to the group being all female, if we are to accept Coates’ ideas on communication, or may be to do with these objects being craft. Certainly the women had no problems merging usefulness and aesthetic expression, or in separating them when appropriate [22].

Risatti’s argument for the craft object chimes with Ingold’s account of the coming together of nature and culture in the very act of making. He argues that craft has both a ‘natural’ and a ‘social’ life, saying that “more properly the purely functional in craft is never pure but is always latent with meaning” [34]. I would add that the reverse is also true, that craft is never entirely autonomous even at its most modern.

CONCLUSION AND FURTHER WORK

Sandra Alfody states in the introduction to *Neocraft* [7:xxi] that: “We have a long way to go before we can discuss the differences between individual and collective craft production, authored and anonymous craft objects, and how to level the playing field for crafts in our globalized economies” – and in addition, she suggests we need to reflect on how feminism is being dealt with. These are areas which the protocol has not dealt with, and which largely are missing from today’s craft literature. Further, one of the most obvious aspects missing in the protocol is an explicit consideration for the role of touch, although conditions four and five – processes of internalization, and embodied process – allude to it. This

omission is being addressed through current and proposed work with a group of textile designers working with new technologies [11]. Metcalf talks of Wagner's synaesthesia in opera production, saying that we "do not consider how sight, touch and hearing can be organized in a unified composition" [30:28] – but we find in language and neuroscience [37], and in the research of, for example, the Glasgow multi-modal interface group [13], some indications of what this kind of research might look like.

In the end such a protocol is a product of our own education and experience – this protocol is a product of my journey from a (fairly conservative) training in jewellery through encounters with interaction design to the facilitation of interdisciplinary textile projects, all within a Western historical framework and employing a pragmatic research methodology. Where other models differ or have similarities, we find corresponding differences and commonalities in outlook formed by practices of making research. The most satisfying models are of course those that speak directly to our own experience, but the most rigorous are those that reveal their own processes of evolution. In the end, the stated aim of this protocol was to improve the awareness of design when employing craft to approach authenticity. It sought to show that a craft approach to production would provide a context for a craft approach to consumption. That is, that the creative engagement of the process (creating meaning through action) might be continued through the craft object as undecidable thing, as the "the commitment of the maker to the work is an invitation to the viewer to reciprocate with a similar level of commitment" [22:31].

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Amplification of Energy

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ABSTRACT

Amplification of Energy explores the potential of alternative energy solutions for fashionable wearables. The research explores renewable energy sources and localized energy derived from and around the body focusing on the harvesting of wireless energy. The current manifestation is dynamic garments. In the context of the installation of such dynamic garments we use the seductive movements of ferrofluid to symbolize the use of oil as a non-renewable energy source, and animate the garments to represent the clean future. Using custom electronics, shape memory wire, and linear actuators, we metaphorically display the 'lightness' of localized energy sources through the animation of a set of garments.

Keywords

Fashionable technology, localized energy, mechatronics, sustainability

INTRODUCTION

Energy dependence has been a problem since the first Industrial Age where man relied on machines for production till today, where wars are fought over resources like oil, gas and coal. Therefore, Amplification of Energy proposes a new form of thinking towards energy, where an individual is no longer dependent on a single source but collects and harvests from a localized self through energy amplification. It is a research project that explores the potential of alternative energy solutions for fashionable wearables to the current unsustainable process of extracting finite natural resources to accommodate the growing population and economy. "Fashionable wearables are 'designed' garments, accessories, and jewelry that combine aesthetics and style with functional technology [17]."

In 1977, Buckminster Fuller quoted: "... within ten years while concurrently phasing out all further human use of fossil fuels and atomic energy. ... It can only be accomplished by a design revolution which produces so

much higher technological performance per each unit of resource invested as to take care of all human needs" [6]. We envision that the design of energy producing fashionable wearables can in turn require less energy for their effective functionalities will enabling a more sustainable and clean future envisioned by Fuller. We aim to produce dynamic garments that focus on the harvesting of radio frequency (RF) energy, as well as look into other localized energy sources. As efficiency improves we will one day be able to harness omnipresent ambient RF radiation.

The latest physical manifestation is an installation of animated garments that exemplify the possibilities of powered interaction and ready-to-wear design. A video of ferrofluid as the backdrop shall convey oil as a metaphor to exemplify the finite resources of energy that are harming the environment and human life, causing social and political turmoil [18].

Methodologically, our process is based on the iterative development processes subject to peer-review and user testing. Finally, the results will be discussed through the possibilities of current technology and manufacturing techniques, as well as the viability of using fashionable technology to harvest localized energy as a sustainable renewable source.

RENEWABLE ENERGY

Renewable energy can be defined as energy from natural resources, such as sunlight, wind, rain, tides, and geothermal heat, which are naturally replenished [12]. The first interest in renewable energy started in the 1960s, where the scarcity of coal drove researchers into discovering new ways of harnessing energy, especially solar. However, this research was put aside in the early 20th century when people realized that energy could be extracted from fossil fuels such as oil, natural gas and petroleum [2]. The 1973 oil embargo by the OAPC (Organization of Arab Petroleum Exporting Countries) against America and the 1979 energy crisis due to the Iranian Revolution which severely disrupted the oil production caused a rethink of energy policies globally and brought renewed interest towards further developing and researching on solar technologies [3]. Governments soon

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began offering solar incentive programs and stimulated new research funding and grants, as well as collaborative efforts, such as the National Renewable Energy Laboratory in the USA, Japan's NEDO (New Energy and Industrial Technology Development) and Germany's Fraunhofer Institute for Solar Energy ISE [22].

Localized energy

Our role as consumers of natural, non-renewable energy will be replaced as producers of localized energy environments. The current alternative solutions to natural energy are non-localized and stand contrary to personal freedom. The current trend toward energy harnessing is pulling us toward mobile and agile energy systems. "Energy harvesting encompasses many areas of scientific research advancing the interdisciplinary development of systems for tapping omnipresent energy potentials, in addition to the familiar methods of generating renewable energy [9]." With localized energy comes manipulation of our microenvironments, extending our control beyond the physical. These localized energy sources will include energy from our bodies and environments. Current examples of energy directly derived from the body are through changes in body temperature, breath, blood pressure, movement, and piezo electronics. Solar energy and wireless energy are derived from the environment. Most provide minimal energy but show potential and require further investigation.

Through piezoelectrical materials, mechanical energy may be harvested from any human movement. Examples for piezo electronics are torque driven generators at the joints, acceleration driven devices at the limbs, force or torque (rubbing or bending) driven embedded fibers, force driving switches in the soles of shoes or boots and force driven harvesting through chest expansion during inspiration [6]. Researchers at the Georgia Institute of Technology are embedding tiny piezoelectric nanowires on flexible polymer sheets that pump out electricity when the sheets are squeezed [4]. Nokia patented the piezoelectric kinetic motion harvester that is designed to provide little sips of additional power to portable electronic. This energy harvesting method can be translated for use in fashionable wearables in the future.

Despite their low efficiency, solar panels are the current alternative energy source used in fashionable technology [16]. But advances in transparent solar panels and solar fabric will enable their use in fashionable wearables. What we propose however, is utilizing techniques found in solar energy and adapting them for ambient wireless energy use. Wireless energy comes in several different forms such as radio frequencies, light spectrums and microwaves. In particular, we will be focusing on radio waves, which are a type of electromagnetic radiation with the longest wavelengths within the electromagnetic spectrum [8].

Wireless radio frequency energy harvesting is similar to solar harvesting in that energy is converted from a waveform into a DC equivalent. What makes RF wireless

energy harvesting unique is that these waves are omnipresent and do not require direct line of sight as solar sources do. Non-textile industries are currently utilizing these technologies to create sensor devices that do not require battery changes or wired communications [14]. Wireless charging works on the electromagnetic spectrum of energy. Electromagnetic frequency while not as efficient in its current state has the ability to work regardless of the weather, temperature or environment. Harvesting antennas can be easily embedded within garments. Conceptually, battery packs can be completely charged off of ambient RF radiation [5][15]. A wireless charger and broadcasting unit can provide wireless charging within a designated area like the installation space. As efficiency improves, this type of device will one day be able to harness omnipresent ambient RF radiation.

Along with potential uses such as actuated garments, the medical industry is interested in using this technology to charge implants, as the radio waves naturally penetrate the human body. The combination of functionality without visual or environmental impedance makes wireless energy harvesting ideal for wearable garments [11].

CONCEPT

The manifestation of the research and explorations of localized energy environments through and around the body is an installation of dynamic garments. The installation is metaphorically using ferrofluid (magnetic oil) to convey oil as the current finite source of destructive energy, as well as visualize the electromagnetic spectrum that is associated with radio frequencies. The final iteration of the installation should show how the harvesting of ambient-radiation around the garment would mobilize and exaggerate the movement of the wearer, a seduction technique used by other animals to project statues and beauty. The new energy will permeate the garment and will amplify the movement of the wearer. Ferrofluid is animated in the landscape behind the garment. This self-sustaining and regeneration of energy is a concept that we are continuing to explore as a method to traverse the current seductive nature of oil and remove our dependency on such natural resources.

Methodology

Our approach towards this project will be through iterative development process. Iterative development process is a method of inquiry where the researcher creates several similar repeated designs with slight variations so as to quantify and observe the change in each sample. This approach is useful to our project as we can observe what materials can be used to optimize and maximize the efficiency of amplification, and such methodology can be easily implemented with different criteria to discover other possibilities for renewables.

Development Process

Our development process began with an in depth discussion about the future of wearable's and the role technology could play with in the context of improving the human

condition. Consideration was also made on current trends in fashion and technology towards sustainability, re-use of existing materials and becoming more eco-conscious [20]. Consequently, the conversation lead itself to how seductive oil has been as an energy resource. Years after becoming aware of the potential of alternative energy solutions we are still heavily drawn to this finite fossil fuel.

Hand drawn sketches of the potential shapes and look of the garment allowed for us to visualize the direction we could take in order to direct the attention of the viewer toward a particular movement and/or transformation. While interested in the aesthetics of the garment, more important attention was being given to the transformation. By incorporating transformative elements within the pieces, we hope to help visualize the amplifying potential of energy harvesting. One of the ways we explored the amplified movement of the garment was through a miniature scale model and time-lapse video (Fig. 1).



Fig. 1. Time lapse of garment movement

Oil constantly came up within the dialogue of the context of our project and research. Visualizing the oil somehow would allow our audience to become aware of our natural obsession toward using this resource without regard to the radical outcomes. It became evident that ferrofluid (a magnetically polarizing liquid) would be a great metaphor because of its aesthetic qualities being similar to oil. Provided that ferrofluid is a toxic liquid [13] we chose to incorporate footage of our experimentation as part of the installation. Figure 2 is a mockup of the ferrofluid footage within the installation of the garment(s).



Fig. 2. Amplification of Energy mock-up of installation

GARMENTS

The garments will be exhibited as an installation using sculpture-like dress forms. The animation of the garments shall conceptually narrate the movement found in nature; lightweight, clean, and airy with the use of renewable energy.

First Iteration

Our first prototype (Fig. 3) was an experimentation of embedding the different technologies, which are shape memory alloys, linear actuators and customized circuitry components. Through trial and error, we explored and discovered the best application of the different technologies within the garment. Special technical attention was needed to automate the individual transformations on a loop without requiring constant draw of electrical power.



Fig. 3. First prototype of garment with embedded technologies

Wearable technology that is to be embedded inside clothing must deal with a variety of constraints such as size, energy efficiency, and recharging capabilities. At the same time, in order to amplify a fantastical idea, the garments need ample power. Working under these constraints, we have chosen to design a small, all encompassing pack that can be appropriately placed on the body in order to minimize restrictions [7].

Before discussing technical choices made a more in depth analysis of the technologies is warranted and the extensive need for energy for these choices. Shape memory alloys (most often made of Nitinol) are a specific type of metal alloy with physical memory. The alloy can be bent and twisted, but once heated to a specified temperature the alloy will return to its original shape. This technology is very useful for garments, as the alloys remain flexible when not heated. Memory alloys are not without drawbacks. The amount of energy required to properly heat memory alloys increase with alloy thickness. Thin alloys are easy to heat but are unable to move against anything but the smallest of forces. Larger alloys are able to make very forceful motions, but they require more energy than can be provided by a mobile garment, and additionally the amount of heat given off by the alloy is difficult to deal with. This heat can cause wear and tear to the garment, or even worse can injure the wearer.

Linear actuators require larger amounts of voltage, as they function in a traditional fashion using small motors and gears. Special batteries are required to power these actuators, which is problematic, as most microcontrollers are not designed to work with such large voltages. Additionally linear actuators are rigid, placement on the garment needs to be wisely chosen in order to prevent interfering with the user.

Through the experimental phase of producing our first iteration of amplification of energy, we were able to address certain technical issues, as well as redefine the role our garments can play in support of sustainably and renewable energy. The dichotomy of using both organic cotton material fabrics, along with synthetic fabrics, stresses the reality of our energy use today.

Second Iteration

In response to critical feedback from academic faculty and industry members, we concluded that the use of multiple transformative elements within one garment proved to be distracting and over processed. Our approach to the second prototype(s) was to create three individual garments, with each owning a particular transformative movement. These elements were emphasized with the use of a contrasting color, deep pink, set against a color palette of earth tones (Fig. 4).



Fig. 4. Color palette

When considering the shape of the second iteration of our garment design, ready-to-wear became an important element. Many fashionable technology projects or garments in the past have had a very mechanical and/or craft-like aesthetic that were untrue to the concept of our project. We want our garment to be accessible, for our patrons to

imagine themselves wearing our garments and becoming centralized energy solutions themselves. Imagine the possibility of detaching your energy use from the “grid”.

Our fabric choices also evolved to be more exemplary of the dichotomy of synthetic and organic. The orange-brown fabric is a color changing synthetic fabric that is dark brown (almost black) and becomes orange when stretched and pulled. The white fabric is of a cotton-nylon blend that is a hybrid combination leading to the grey organic wool and the deep pink silk. The cut of the garments were influenced by the symbolism of line and shape. The natural fabrics were cut to have more curves or straight lines while the synthetic skirt has extreme diagonals. Creating a beautiful contrast, while working uniformly as a full outfit.

Once the physical movements were determined, a small programmable microcontroller was required in order to control the movements and bring life into the garment. Arduino physical computing is well known in academic environments, except these devices are rather bulky, and cannot natively handle large amounts of current or high voltages. However, through the use of custom fabricated hardware we were able to create a low profile solution, capable of providing the high voltages and large currents needed to power both the memory alloys and robotic actuators.

Two different actuators were chosen for our three garments in order to provide distinctive and unique motions. It was found that memory alloys worked well in conjunction with gravitational or structural forces. However, they are only capable of providing a force in one direction, either gravity or natural properties of the garment would be required to pull the garment component back into a resting position. In terms of wearability, there was a slight loss of mobility due to the stiffness of the actuator (vs. the flexibility of memory alloy) but worked in our concept of an installation.

Figure 5, is the garment with the fin like transformation in the back of the grey wool jacket. The back is all grey until the fin reveals a deep pink color.



Fig. 5. Garment #1

The second piece (Fig. 6) is another grey jacket with the front right panel opening itself to expose the beautiful deep pink detailing.



Fig. 6 Garment #2

Our third piece is the white shirt underneath the jacket. Figure 7 shows the exposure of the deep pink of the under lining of the petals.



Fig. 7. Garment #3

These pieces can be worn with the synthetic fabric elastic skirt (Fig. 8).



Fig. 8. Full (concept) outfit

Aesthetically, we are pleased with the second iteration of our prototypes (Fig. 9). We hope that through time, possibilities of this integration of technology within ready-to-wear fashion can become accessible to the public.



Fig. 9. Amplification of Energy set of garments

Installation

The installation (Fig. 11) will be enhanced with projection of the ferrofluid on a large display behind the performers. The decision to incorporate the different physical elements of this piece was to create an environment for the garments to live in. We would hope that the powerful images of the ferrofluid would help viewers consider the commentary being made with these series of smart garments.

The video is a sequence of experimentations of the ferrofluid with different metal components to visualize the dynamic properties of this magnetic ink (Fig. 10) [1]. The polarizing and highly reactive elements of the fluid beautifully encapsulate the otherwise invisible magnetic field.

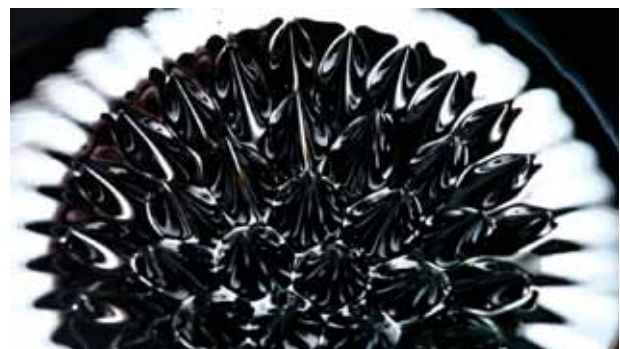


Fig. 10. Ferrofluid video stills

The garments are exhibited as an installation (Fig. 11). The sculpture-like dress forms are made of collected wood to focus on the sustainable concept of the project. The use of wood shall also represent the origin of oil, which began

with plant fossils. The video of our ferrofluid experimentation is projected in the background of the installation.

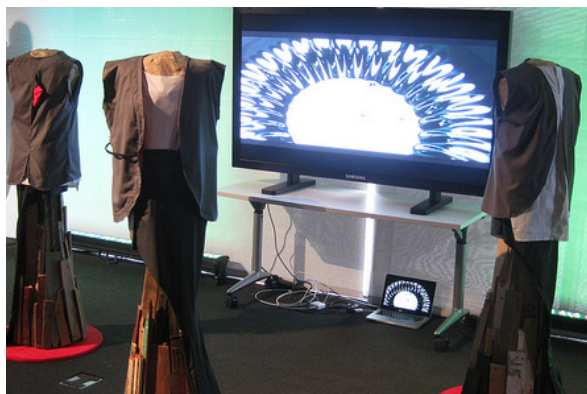


Fig. 11. Garments - installation display

CONCLUSION

We believe that by creating an interactive live work of art, attention and awareness can be drawn to the importance of localized energy and the direction that we may take in the future as we continue to populate and require more energy resources than our planet can sustain. Our essential goal in this project is to bring awareness to sustainability and renewable energy through wearable technology. The individual choices we make daily, from our clothing to the foods we buy, shape the amount of pressure we place on the direction industries take toward sustainable practice. Amplification of Energy will inspire patrons toward making those important decisions and ignite conversations that may lead to alternative solutions.

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Spatial Explorations in Interaction Design

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ABSTRACT

This paper examines spatial explorations in interaction design. Taking its offset in a design research program, SMUI – Spatial Multi-User Interaction, the paper discusses methods and challenges met when working with design explorations guided by the program. The design research program takes a stance in existing resources, investigating how spatial aspects in combination with digital material support simultaneous multi-user interaction in public and semi-public space. The challenges concern involving spatial aspects in the design process and to respect the context of the computational object and the characteristics of the place. The design explorations, methods, model and definitions will be presented and discussed together with why spatial aspects matter in interaction design.

Keywords

Interaction design, space, architecture.

INTRODUCTION

The traditional computer forms change and become part of our physical space, and as computation manifests its expressions in the spatial, physical realm, interaction designers have increasingly come to work with spatial IT-artifacts. Though, physical space has not been a major topic in traditional human-computer interaction (HCI). The embedding of information systems into our physical surroundings increases the importance of an understanding of space in relation to computational objects for interaction designers. Space is an unavoidable aspect that needs to be designed and not just as a natural consequence of being situated and embodied in the physical world (Lykke-Olesen 2007).

Adding spatial aspects to information technology brings the interface out into the room and expands the role of the interaction designer to develop structures and form as well as composing situations for its users. As architects are faced with problems of creating meaningful situations beyond stones and windows, interaction designers are faced with creating meaningful situations in both physical and digital space using IT as the primary design material. IT as a design material can be considered as non-physical and non-spatial, however, when designing spatial interfaces, physical materials come into play and designers must understand how the properties of IT relate to spatial properties and boundaries as design materials. With the rise of pervasive and ubiquitous computing, the number of IT-artifacts taking up room in physical space increases.

Physical space is important in interaction design, as it grounds the most basic experiences upon which we create understanding. Spatial literacy, i.e. concepts and understandings of humans' relation to their physico-spatial surroundings (McCullough 2004) and the intelligence we use to make sense of the world (Gardner 1993), is more or less highly developed in different people. Human reasoning is based on our perception of the physical space and its objects (Grivas 2008). We understand and navigate in physical space more quickly than anything else. We also communicate through physical space, the way we position our bodies and the fine conscious or unconscious gestures provide meaning and is a part of our language.

SPACE IN INTERACTION DESIGN

So, how to define or even talk about space and spatial perspectives in relation to interaction design? When Brunelleschi invented linear perspective in about 1425 (Cooper 2007) as a geometrical technique to illustrate depth in representations of our world, then there existed no digital space yet and concepts such as “under”, “distant”, “outside” and so on gave meaning. Linear perspectives create a space through a “window” where the centre of attention is pre-decided for the viewer. Representational space relies heavily on strict laws, reason and hierarchy, and illustrate how we perceive the world around us. In contrast to this is abstract space. It can be one or multi-dimensional and is more a representation on how we experience the world

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rather than seeing it. Traditional work based HCI and WIMP interfaces are leaning more towards the representational space, with strict hierarchies and where the shortest path between point A and point B is the goal. Now interaction design is moving away from this efficiency focus towards abstract space, like the twentieth century artists such as cubists tried to move away from strict perspectives and coherent depth. In cubists art-work the objects are broken up and re-assembled in abstract forms, showed from several viewpoints to represent the subject in a greater context. Just like cubism, the goal for interaction design is not to represent the world as we see it with our eyes, but as we perceive it with all our senses and from different angles and perspectives, to provide a more multi-faceted experience.

Before the Bauhaus period (Forty 2000) space was understood and defined as a container that could contain other containers (spaces). During the Bauhaus period space was seen as a continuum where spaces dynamically would intertwine and flow among each other. This continuous space was changed by the observer moving in space. Now ubiquitous computing and virtual augmentations expand the understanding of space further, with the dynamic nature of digital systems and interfaces the perception of space is not only changed by the observers moving point of view, but the space itself is dynamic, both regarding appearance and functionality. Space becomes defined by the potential functionalities afforded by areas or spaces within a continuous space, and not only as a container defined by a three dimensional set of physical and virtual boundaries. Space and the physical environment is a design resource open to virtual and interactive augmentation, and therefore we have to accept and play with the properties of physical space and their influences on different types of interaction.

Dourish (2004) suggest that context is continually renegotiated and defined in the course of action. The context construction is dynamic and space and place is distributed and depends of the perspective of the viewer. This can seem impossible to design for, but this understanding is helpful, and points to the importance of involving context in all parts of the design process. An idea is constructed during the design process, so framing the context is about exploring and discussing what there is now and the importance of it. Further, context can trigger new ideas, or improve existing products, but the context also affects the design, “everything that a design affects, or that the design is affected by, forms the relevant context” (Ylirisku & Buur 2007). As pointed out in (Brynskov et al 2003), all real world problems involve several perspectives, though a developer can focus on one perspective, all other must at some stage be addressed as an integrated part of the design work. Methods and models such as for instance the Four space model proposed below in this paper are necessary tools when considering the complexity of the multi-faceted context matrix. This is also the basic

motivation for forming the SMUI – Spatial Mutli-User Interaction design research program.

As a research program for experimental design SMUI - Spatial multi-user interaction is concerned with the type of dual design that computational technology introduces. The basic characteristics of computational things lie in the fact that their expressiveness, their appearance in use, depend on the execution of programs and its manifestation in a physical material. Design of computational things thus necessarily involves components of spatiality; questions about working models for a design practice where the digital and physical aspects of computational technology as a design material are central issues. This motivates experimental work where special attention is paid to spatiality as a basic design parameter.

DESIGN RESEARCH PROGRAM SMUI – Spatial Mutli-User Interaction

A design research program seeks to make a difference, to change something. It is not as much coming up with an answer, as it is to find alternatives and possibilities for a different future and design practice; to make concrete what is possible. The experiments expand and express the possibilities of the design research program in different ways, and for the program to answer both ‘what’ and ‘how’ then it is important to also describe the process of how the alternatives develop. Hallnäs & Redström highlights the constant need for new design research programs that guide and develop practice by opening up new design spaces (Hallnäs & Redström 2006). The guiding design research program here is defined as Spatial Multi-User Interaction, where practical design experiments have generated new theory and methodology. The design research program both sets up the border for what should be investigated, a space spanned by the experiments, but also guides the experiments into expanding that space.

The design research program has implicitly been the base for design experiments, and the design experiments have explicitly been the foundation for further development of the design research program. The goal with the research program is not to come up with solutions or potential products, but to open up the design space and find alternatives to established practices. The alternative design examples consist of prototypes, concepts and methods. SMUI aims for creating a space for reflecting upon the current design discourse concerning interacting with technology in people’s everyday life in the context of public and semi public space. The experiments does not completely span the space of possible design alternatives in line with the program, as there will always be questions and experiments left when the design research program is over. The experiments performed in this design research program are colored by the constellations of people and stakeholders involved in the different projects, by the materials at hand, time and of course by the program. In the experiments, the design space is spanned not only by the design examples

but also by the methods and techniques developed within the experiment.

THE GENERAL PROGRAM THEME

Spatial multi-user interaction refers to the design of computational things with a strong focus on several simultaneous users and spatial aspects, and where a focus on spatial aspects is a central design variable. The central theme is interaction design with a clear focus on the appearance of physicality and several simultaneous users rather than design for efficient use with its focus on digital aspects and single users. It is a design research program that extends the traditional work practice based HCI into playful and leisure based interaction design. Spatial multi-user interaction supports human communication through computational technology based on democratic values, where several simultaneous users do not have to take turn in being in control and where interaction is based on movements of the human body. As opposed to work practice based technology designed for efficiency, this is technology where the human body in physical space is in focus for playful and leisure based interaction.

Spatial multi-user interaction takes a start in people's way of expressing themselves physically; individually and together with others. Here, the human body with its multiple intelligences is a given, and the computational things attempt to be designed within the limits of the human body's expression. To support the user in several of her intelligences by exploring both the physical, digital, social and interaction space, is taking advantage of the potential of the materials to a great extent.

SMUI is a design research program that inquires into Spatial Multi-User Interaction issues in terms of design practice and everyday life. Through design interventions that criticize and introduce alternatives within certain situations, the aim of SMUI is to influence the practice of designing technology for people's everyday life by investigating the context of and interactions in public and semi-public design space. The design interventions and the design methods become a platform for exposing existing and hidden habits, norms and materials, as well as for proposing alternative actions and views. The examples have been developed through practical experimentation and guided by the design research program.

Using what is already in the context; such as materials, values, traditions, norms, expectations, problems, behaviors and technology, are essential and a vital part of the design research program.

DESIGN EXPLORATIONS

Here follows a short overview of the design explorations guided by the design research program. The explorations are developed within different projects and contexts, but are all situated within public or semi-public space. To clear out what is meant by this, some definitions will follow.

Public space is freely accessible to the public and is intended for social interaction, relaxation or passage (Cybriwsky, 1999). Such spaces have always been important to city life routines as well as the cities overall reputation and image. Public space is open, free and accessible to all, no matter of gender, social status, race, or age. Traditionally public spaces are interactive, social, democratic and self-organizing. Examples of this are city squares, pavements, open parks and streets. Shopping malls appears to be public space but is actually owned by private interests, and are private space with open access to most people at restricted hours of the day. In all types of public space, there are implicit (street) or explicit (governmental) rules and laws. The experiments dealing with public space are MIXIS and Bthere, presented below.

Government owned buildings such as museums, schools, science centers and libraries are public space, but as they have restrictions on opening hours they are here considered as semi-public space. *Semi-public spaces* are not necessarily free, they have restrictions and someone has an agenda with these spaces. The experiments dealing with semi-public space are the Interactive Children's library, Families at Play in the Library, Mission from Mars and iSchool, see below.

Private space is individually or corporately owned. It can be a private building, an office or a mobile device that supports the user to perform private activities in public settings. Advertisements from privately owned buildings can create a feeling of a public space to be private. The experiments playing with private space in public space is the MIXIS project.

An overall experiment dealing with all three spaces is the Missing link workshop method presented below.

iSchool

The vision of the iSchool project is to develop software infrastructure, GUI's and spatial concepts for new interactive school environments. Two prototypes were developed; eBag a digital counterpart to the physical school bag and eCell a learning environment for shared interaction. Also, a method for gathering user requirements by using a narrative space was developed, named "Mission from Mars", see Fig 4 (Dindler et al 2005).



Figure 4. Pupils broadcasting (a) and the watching Martian (b)

The Interactive Children's library

The Interactive Children's Library project vision to develop prototypes of new IT services and physical installations embedded in the physical spaces of the library that challenge, support and promote curiosity in kids play and learning activities. Several new design concepts all based on the motto "taking the physical aspects serious"; a new way of thinking in interactive library environments, and two computational prototypes were developed, StorySurfer and LibPhone, see Fig 1. StorySurfer is a 5x3,6 meters spatial book browsing installation for children, and the LibPhone enables children to annotate physical material (books) with digital recordings. Both prototypes mix the digital and physical to create spatial interfaces for children's multi-user simultaneous interaction and information sharing (Eriksson & Lykke-Olesen 2007) (Lykke-Olesen & Nielsen 2007).



Figure 1. StorySurfer (a) and LibPhone (b) in use.

Families at play in the Library

The project investigates how different types of installations can support families playing together in the context of public libraries. The interactive installation U.F.O.scope seeks to stimulate the lust for families to explore the unknown together on unfamiliar ground, while also discovering the physical library and its different types of resources such as text, video, sounds and pictures, see Fig 2 (Eriksson 2010).



Figure 2. The U.F.O.scope at play in the library.

MIXIS – Mixed Interaction Space

Mixed Interaction Space (MIXIS) is an approach to gesture based interaction on mobile devices, where the interaction space is expanded into the physical world. MIXIS uses the camera in mobile devices to track a fixed-point and thereby establishes a 3 dimensional interaction space wherein the position and rotation of the phone can be tracked, see Fig 3. The fix-point can be anything that stands out from the surroundings, a colour or pattern, or even the user's face. Several prototypes have been developed based on the MIXIS concept, such as ImageZoomViewer, DrawMe, DRoZo, Pong and PhotoSwapper. Several new interaction

concepts have been generated, for instance drawable interfaces, face tracking, expanding the interaction space with mobile devices, designing for public interaction with private devices using a market place metaphor, and a conceptual framework for movement based interaction in camera spaces (Eriksson et al 2005).

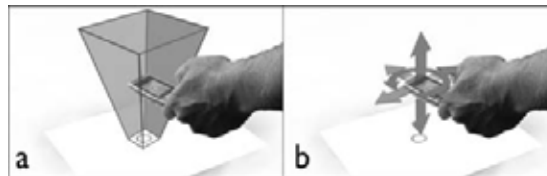


Figure 3: (a) Diagram of the MIXIS (b) Diagram of gestures.

Bthere

The goal for the *Bthere* method is to enhance context-awareness in design, by pushing the design process out into the context, and was developed for a workshop held with architectural students. By creating a deep and layered analysis of the context and the inhabitants while being in the context, the identification process of the tasks and behaviours can be adopted immediately in the design ideas. The general concept of the method is to divide a site and its surroundings into different layers, and thereby unfold aspects and find depths that are not visible from the surface, see Fig 5. *Bthere* aims at focusing on one thing at the time, discuss it from different perspectives, and connect them, instead of trying to study and register everything simultaneously (Eriksson et al 2005).



Figure 5. Bthere concept (a) and result (b)

Missing link

"Missing link – designing for dependency" is a hands-on workshop method developed for interaction design students, where several groups design components that will be combined in a number of unforeseen ways, creating an interactive light installation, see Fig 6. During the education, interaction designers develop projects from concept to implemented prototype, most often with low constraints, and as standalone systems. In this workshop, the students design and develop a component that works within the rules of an overall system interface. Each component work on its own and at the same time is part of a full scale system, in which it reacts to and depends on the other and different components of the system. When the components are connected they are no longer in control but must obey the rules of the system as a whole. This confronts questions on how to give up control of your design and at the same time in a creative way exploit the available rules of the system context. (Missing Link 2004)



Figure 6. Missing Link result (a) and concept (b)

UNDERSTANDING CONTEXT

Within interaction design, and especially with the growth of context aware systems, the physical world is used as part of the system or interaction, both directly or indirectly. In context aware systems design the difficult aim is to create systems which performances are reliably in the sense of responding to what state the real world is in, and what users really wants to happen (Pederson 2003). The challenge, though, lies not only in making the system aware of the real world state, but also to make the context aware of the system and the implications of one's actions (Bellotti & Edwards 2001). The real world context is though something very complex, why the tendency is to focus design on simple physical measures such as temperature, location and time of the day, while interpreting for instance the social domain seems more difficult (Pederson, 2003). To avoid systems to become superficial and insensitive to reality, context has come to play a more important role in interaction design, and will here be further discussed.

There are many variations of definitions what context really is, as it can be applied in many contexts, and what the context of a computational object is, such as (Dey et al 2001), (Brynskov et al 2003), (Dourish 1996), but the definition of context is of course context-dependent itself. The definition of context differs if you come from robotics or from ethnography, and if you are in the initial or final phases of the design process. The SMUI design research program leans more up on Jones notion of "the total situation" (Jones 1992). In (Jones 1992) this is not used for describing context, but describes the intentions of his design methods, that it is about the design of 'all-things-together', the 'total situation', meaning the functions and uses of things, the 'systems' into which they are organized, or the 'environments' in which they operate (Jones 1992). The scale of design today has expanded from things to 'intangible designs', the operating wholes of which modern life is being formed and made; such as systems, software, flows, communications, communities etc. The change in scale is also a change from designing-in-space to designing-in-space-and-time, and thereby the way things are used, or intended to be used becomes as much designed as does their shapes (Jones 1992).

So why is context vital in interaction design? The move to consider context of use builds upon previous trends such as in developing mediaspaces at PARC and the emerging notion of Ubiquitous computing (Weiser 1991) and small-scale devices that exploit context to provide ambient awareness (Ishi & Ullmer 1997). The central design material

in interaction design is information technology, which is both abstract and concrete, both software and hardware. Computational artefacts, have a dual nature in being both physical and digital. Most often existing approaches to design tend to focus on only one of these aspects, or one after the other in the design cycle, and more rare to consider both physical and digital design simultaneously, equally important, feeding into and depending on one another. When designing these dual natured artifacts there is also a tendency to focus on isolated objects, not respecting its dependency to their context, and does not involve the context in the sense that it is a vital part of its design and expression.

Four Space Model

As a try to unfold and identify the context, a new model has been developed, guided by the SMUI design research program and informed by the design explorations. The Four Space Model is an analytical tool, an attempt to divide the findings and the prototypes into different design spaces. Working with information technology as a material for design means working with software, hardware, traditional physical materials and social aspects. The model aims at making this fact more visible during the entire design process. The model can be used as a tool in the data collection phase, in the design phase, for definitions and in discussions. The model is a try to mark out that all the four design spaces are equally important when designing computational things, and especially for spatial multi-user systems. Here follows definitions of the four spaces:

The Interaction Space

This design space is spanned between the existing technology and the physical human abilities. The interaction space is defined as the sensor reading space where movement, fix points and inputs can be sensed. On the user side, inputs are inspired and constrained by the multiple intelligences and functions of the human body. On the technology side, a sensor reading space can for instance be a microphones ability to take up sound or the camera space, meaning the area where a sensor in this case a camera can see physical input such as movement or appearances. By investigating and knowing the borders and possibilities of this space - static or non-static, aware or unaware - it is possible to use the full potential offered by the sensor and the interaction. There are unlimited mapping combinations between the sensor and the interaction. This can be a huge inspiration to the design process, i.e. trying out different combinations to make less traditional computing and more everyday human action like. The interaction space starts out with the technology and bodies at hand but extends extensively by curious investigations enlarging the possible design space.

The Social Space

This is the space where people meet; the social design space includes technology but spans between people. This is where space gets meaning and transforms into places (Harrison & Dourish 1996). The social space is defined as where humans act, live their everyday lives and co-operate; it includes attention, activity, intention, understanding, communication and place. This is not a space for designing the user or the user's behavior, this is the space where designers start with the user as a reference point, and support the user on the level of the user. Here people communicate with several others simultaneously; long distance by technology, and closer by face-to face and with body language and gestures. There are hidden rules, hidden messages, and value signs. Not addressing this design space means missing out on human behavior and can lead to designing the user, not just the system. This design space can be used as inspiration, for instance to reveal the potential in people's habits and behavior. The space have a great impact on how people will live and communicate, meaning what relation they will have to the computational thing and to each other using it. To investigate the aspects in the social space, a deep and nuanced analysis is needed, as appearances are deceptive.

The Physical Space

This design space spans by physical constraints, and contains all types of visible things such as humans and computational things. The physical space is defined as things, context, personal gadgets, appearance, location, physical interaction, physical time/space, or just everything you see in the environment. This is where the system meets the user, and the physical context in which the computational thing will live. See the potential in people's gadgets and behavior, use that as a base to find new ways of interaction, and design the technology, not the user. The embedding of information systems into our physical surroundings makes understanding of physical space in relation to computer mediated activities foundational for interaction designers. When designing spatial interfaces, physical materials come into play and designers must understand how the properties of IT relate to spatial properties and boundaries as design materials. Spatial and physical aspects are important in the final system, and must therefore be carefully attended to in the entire design process. It is the responsibility of the interaction designer to care for the physical aspects as well as the interface aspects in design.

The Digital Space

This is the design space where different computational things communicate with each other and with the users. This design space spans by the communication of the different computational things and their output. The digital space is defined as projections, communication protocols, computer model, infrastructure, relative time/space, augmented space, and machine communication. What is

happening in this space can be communicated to the user by various kinds of feedback. For instance, an individual cursor on a shared display can contain information about the input feedback previously provided by the interaction device.

About the FOUR SPACE model

The Four Space Model is meant to be used as a practical tool in several ways. When doing observations, the four spaces can be used as glasses, or reminders of what aspects to look for, so that no aspects are forgotten. This is four ways of experiencing and observing a space. When analyzing the observations, the model can be used as a discussion tool; discussions will likely appear when presenting observation from a certain perspective, since others from the design team have probably noticed some aspects differently from you. This can give very fruitful discussions, here it is possible to see if any of the four spaces are overweighting, and analyze why. Further on in the design process, the model can be used as an inspiration and brainstorming tool, for instance by trying to expand the different design spaces in different ways, or to combine them. This is a way to expand the possible design space. At later stages in the design process, it could partly be used as a design decision tool, as for instance, if there are certain aspects that should be enhanced due to project goal. After the design project, the model can be used as a tool to evaluate what type of aspects most were inspiring for the project, what aspects stood out the most in the start and how this has changed during the design process. This is important both when presenting the project, but also when evaluating the constellation of the design team and work process for future projects.

The model has been used in various degrees in combination with other methods in different design research projects. The method has also been tested more focused in two different day workshops, initially with primarily architect students, and later on with interaction design and game design students. Both workshops concerned designing for public space. The different types of designers used the method differently: the architects easily made use of the physical and social space, while the game designers had a more engineering approach and used physical space as framing for their creativity, and had a hard time using the social space when gathering data. Though in their design explorations, the social space comes more into play, highly inspired from discussions with others. The interaction design students grasped all four spaces in a very balanced way, even though there was an overweight in the digital space, at least considered to the others. What was really interesting to see was how interaction and game design students by using the Four space model took one step away from their safe environment primarily designing graphical applications and stand-alone gadgets into creating more spatial designs, where the interaction is more spatial, and also more spatially and contextual considered in their

reflections. Using the four space model, the architect students took a huge step into a previous unknown world to them, and could actually use digital design materials in their concepts and design ideas for the first time.

DISCUSSION

So, to have a critical view on this, who would use the Four space model and what design team would put effort into separating findings in different design spaces? As with all design methods, it is perhaps not always suitable or possible to follow the entire Four Space model, but rather to join it with other methods. Jones has a principle when it comes to choosing design methods, and that is to choose whatever method will tell you what you don't know, but need to know, in order to proceed (Jones 1992). Experiences from the design experiments and workshops show that investing time into using this model actually opens up the design space even further, and proved to be a good investment before, under and after the design process. The SMUI design research program points to the importance of using the existing digital and physical resources, services and habits as design material, so any means of detecting those are welcome.

Is there a need for more design research programs, methods and models for design? As the field changes and develops, as well as the traditional computer forms change and become part of our physical space, there are constantly new challenges for designers. The classic methods are very useful, but many of them were developed for totally different interaction paradigms, and sometimes there is a need for something to complement these with. As interaction design is about organizing social relations and interactions by means of spatial and digital layout, the challenge is to design spaces for human communication and interaction. Interaction designers design what Winograd (1997) named interspaces, assemblages of interfaces, actors and environments, and contribute to the configuration of the environment of interspaces as well as the interfaces. Dalsgaard & Eriksson (2007) point out that physico-spatial aspects are lacking in design methods, and Ciolfi claim that the way we physically inhabit the environment is not sufficiently considered and that new concerns regarding the many aspects of spatially distributed interaction design must be taken into account, for instance in how we occupy and use spaces (2004). Activity Theory (AT) (Bertelsen & Bødker 2003, Nardi 1996) is a conceptual framework for understanding interaction in context, here space is primarily treated in terms of analyzing the role of space before designing IT-systems and evaluating spatial effects of IT-systems in use contexts after the design phase. The role of space is not recognized in the design process itself. Ciolfi (2004) suggest that the data collection phase should include surveys on the particular spatial arrangements of the environments, and observation sessions focused on the features of the physical space and aspects of place

expressed by the users in that environment. Of course these sessions should be complemented and cross-analysed with more traditional methods. A number of AT-studies have been carried out to present analyses of information systems in particular physio-spatial settings, such as (Bertelsen & Bødker 2001). However, Activity Theory has mostly been applied as a conceptual framework for academic researchers and not succeeded in being a genuine resource for practical design (Bertelsen 2000).

The purpose of any method in designing is to get one's mind to become familiar with the unknown possibilities and limitations of 'the new' before making irrevocable decisions (Jones 1992). The Four Space model presented here is a try to create a more multifaceted understanding of a space, and a try to complement the current design methodologies and techniques that not explicitly consider the importance of gaining a full understanding of the human experience of space when designing interactive technologies that will become an integral part of our physical environment (Ciolfi 2004).

Why public and semi-public space? There is a tendency of making public space more private, by more restrictions, advertisements, control and design. Very few new public places enhance the quality of urban life while also reflecting social problems and other divisions (Cybriwsky, 1999). The trend is rather increased privatization, increased surveillance and increased use of disconnected designs that break connection with local history and geography. There is lesser room for creating your own place in public space, or use it in your own way. This tendency is also partly supported by the development of new technology, for instance by pushing information, wireless networks, surveillance or directing your way. Increased use of private mobile devices divides public space into small bubbles of private spheres moving around. Large displays push information and advertisement for people in public space to consciously and unconsciously consume.

The increased number of shopping malls and more controlled private spaces acts as a filter for certain opinions and people. Urban planning makes public space more suitable for either cars or people, compare for instance the city square acting as living room in Italy to a modern city like Los Angeles with cars everywhere. Different behavior is connected to different zones in public space, for instance drinking wine is forbidden on a bench on public squares, but fully acceptable in a sidewalk café next to the bench.

The trend today is that more and more surveillance and rules are applied to public spaces, and safe environments are definitely preferable, but there must be a balance between freedom of expression and control. Any part of public space can be misused, so introducing new technologies into public space can perhaps increase or decrease this, but at least make it different. It is crucial to believe that when developing and introducing new systems in public space, there will be some degree of self-

organization so that the content is not offensive to the majority of the public. Many types of activities in public space can upset or provoke, such as demonstrations and music, but it also contributes to a lively and inspiring environment, still regulated but partly out of control. To increase the connection between the public space and its inhabitants, it is crucial to establish the ground for place-making (Harrison & Dourish 1996), and believe in self-organizing behavior.

Design both accommodate and effect certain behaviour, use and rituals, but use also shapes design. Design is not just the design of objects, but relations in space and time. This has not always been the case; it was first around the 20th century that space became a subject. Developments in technology, infrastructure and others like Bauhaus started to realise that object of all sizes are related to one another, that there is life between buildings and objects and that meaning is created in use. When churches become nightclubs and railings become skateboard ramps, meaning used to something completely different than what it was once intended or designed for, the designer just has to follow and accept that when the object is designed and built, that is when the process of remaking over and over again starts. A process the designer has no control over, as it is the people, times and surroundings that make that change. The designed thing or space have no fixed meaning but are rather open for reinterpretation, characterisation, personalisation and remaking. The design is used to build the acts that define its use, and interaction design is about designing the acts that define intended use of things (Hallnäs & Redström, 2006). Use and misuse reprograms found space with new functions and meanings (Mazé, 2007). Design compositions evolve over time, and interaction is highly dependent on time, as it is only through use over time that the system and its functions is revealed. An understanding of the consequences of one's actions is built through interaction. The form of objects and interaction are initially designed, as for instance inviting, persuasive, but use is unfolding the form of things. The meaning with design is not to persuade us to act in some specific manner, but rather to pose objects that make us interpret, reflect, act, and participate.

Architecture concerns the organization of activities and social relations by means of spatial layout, a highly relevant source of inspiration for interaction designers (Dalsgaard & Eriksson, 2007). In architecture the focus is on atoms, in computation the focus is on bits, and though they are profoundly different, they must be treated together in interaction design. The goal is to create designs that encourage and support interactions and social interaction in public and semi-public space without dictating any terms of use, following the characteristics of the place and the human intelligences.

CONCLUSION

There is a need in interaction design for understandings of how both the augmented and the physical spatial layout affects the users' experience, behavior and social relations. Current design methodologies and techniques do not explicitly consider the importance of gaining a full understanding of the human experience of space when designing technologies that will pervade and become an integral part of our physical environment (Ciolfi 2004). The role of space is not recognized in the design process (Dalsgaard & Eriksson 2007). Adapting understandings of physical space into interaction design, both in the design process as well as in the designed artifact, may yield new ways of understanding interaction and use. This may lead not only to a better understanding of spatial issues in the design phase, but also inform the analytical phases before and after the design phase. Design experiments are key to gaining insights into spatial design issues. The SMUI – spatial multi-user interaction design research program guide and frame design explorations and methods where special attention is paid to spatial aspects in interaction design supporting several simultaneous users in public and semi-public space. In order to identify the context and what issues are at play when designing, the Four space model is presented.

The SMUI design research program, the Four Space Model and the design explorations presented in this paper can provide a richer understanding of the context and the design material at hand, which is one of the basic parameters for forming the system and not the user. By using the materials and knowledge at hand, it is possible to maintain and enhance the characteristics of the place, but also to create a stronger connection between the digital and physical layers in the space. By focusing on spatial multi-user interaction in interaction design, the use of public and semi-public spaces will be more based on democratic values going from information push to information dialog. The interaction form will change to become more physical oriented.

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Articulating Atmospheres through Middle Ground Experiences in Interaction Design

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ABSTRACT

This paper presents an architectural approach to designing computational interfaces by articulating the notion of atmosphere in the field of interaction design. It draws upon the concept of kinesthetic interaction and a philosophical notion on atmosphere emphasizing the importance of bodily experience in space, presented as middle ground experience. In the field of HCI, middle ground experiences complete the unarticulated spectrum between designing for foreground of attention or background awareness. When “*Articulating Atmospheres through Middle Ground Experiences in Interaction Design*” implications and qualities of the approach are identified through concrete examples of a design case, which also investigates the qualities and implications of addressing atmospheres both as design concern and user experience.

Keywords

Interaction Design, Atmosphere, Background Awareness, Middle Ground Experience.

INTRODUCTION

The emergence of new technologies has throughout history reshaped our built environment and thus, our way of inhabiting space. Within interaction design, researchers have an increased focus on the inherent qualities of the physical environment; qualities that previously have been overlooked in the intersection between physical architecture and technology. In his book *Digital Ground*, McCullough [19] stresses, that pervasive technology does not obviate the human need for physical place and shows that context not only shape usability but ideally becomes the subject matter of interaction design [ibid]. In line with this, Fogtman et al [9] emphasize that an architectural notion of bodies in space can offer much to the design of

collective interaction in pervasive environments [ibid]. The notion of atmospheres, as a means of engaging the sensing subject in its spatial surroundings is one of the architectural qualities, which within interaction design is a neglected dimension of spatial experiences [4]. This is quite paradoxical according to at least three perspectives: First of all, related fields as architecture and performance art have long traditions of working with atmospheres [ibid]. Secondly, the use of technology has shifted from being task-oriented to be experience driven and the focus is on the interaction between people and products including sensual, emotional and aesthetic qualities [11]. Thirdly, there is an increasing interest within theory, as well as practice, in physio-spatial and social aspects of interactive systems [4][9][13][19]. Drawing upon a number of disciplines including philosophy, architectural theory and human-computer interaction this paper discusses the notion of foreground attention - background awareness [30]; which has dominated the view on spatiality within interaction design [14]. The claim of the paper is, in line with [5] that the design of current interfaces seem to be build on the assumption that interaction can be captured in schemata and that the body is merely a mechanical executor. This view, does not justice our embodiment in the world [ibid]. The primary concern of this paper is to bring attention to the overlooked potential of designing atmospheres to the field of interaction design research, addressing how bodily felt experience of shared and socio-cultural space may influence the interaction. The paper is outlined as follows: first the current notion of designing for background awareness is introduced and exemplified by the work of Ishii and others [14][15]. Then the notion of atmospheres is presented based on the German philosopher Gernot Böhme [1][2] this leads to the section of introducing *middle ground experience* denoting bodily experience of space. The design case “Color the Atmosphere” exemplifies through a working prototype a design approach to atmospheres and discusses the relation between foreground, middle ground and background both as design concern and user experience.

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2. RELATED WORK

It is apparent that atmospheres are always present even though we are unable to unambiguously measure the existence of them, we all agree to the fact that they exist. Atmosphere denotes the quality of being present in space and we are not positioned opposite to or outside the atmosphere; but enclosed by and steeped in it [16]. Throughout history we have acknowledged the existence of atmospheres and they have actively been designed for e.g. within architecture and performance art [16][31]. Few interaction design researchers have addressed the topic of atmospheres [4][17][24] but without articulating it as design concern and user experience.

2.1 Designing technologies for background awareness

In the late 90's a new paradigm for interacting with computers was introduced by Ishii and Ulmer to the field of HCI [13]. Criticizing the conventional GUI model for its "painted bits" Ishii and Ulmer presents a TUI model where "tangible bits" gives physical form to digital information [ibid]. One of the aims of "tangible bits" pointed towards designing interactive systems enabling users to be aware of background bits in the periphery of their attention using ambient media displays [ibid]. The notion of designing technologies for background awareness, the periphery of a users attention, is opposed to foreground interaction, denoting the center of a users attention [30]. The spectrum between foreground and background awareness is yet to be articulated. When Ishii et al envision turning architectural space into an interface between people and online digital information [30] they draw upon two design cases [14][15] both concerned with presenting information to the periphery of human attention. The case of AmbientROOM [14] will in the following be used to exemplify the conceptual design idea. AmbientROOM was conducted in a freestanding office room and augmented with several interfaces exploring a multi-modal approach to ambient displays. One of the design concepts is made to inform the number of unread email messages through subtle but audible soundtrack of birds and rainfall, whose sound volume and density are modulated in the conjunction with variation in room lighting [14]. In line with [9] a critique on Ambient Room is raised according to their insufficient ideas on spatiality. Ishii et al refer to *"a personal interface environment designed to provide information for background processing"* [14, p.173] and the use of space is confined to a personal interface. Yet the room is understood as a 3 dimensional space, but the value of the room, as a social and atmospheric space is completely neglected.

2.2 The notion of Atmospheres

Atmospheres constitute our first sensation on entering a space and enable a specific experience of spatiality. It seems fairly easy to name a range of different atmospheres e.g. warm and uplifting or tense and hectic atmospheres. It is less easy to point out what constitutes the atmosphere of a specific space. The concept of atmosphere is by nature a background aesthetic and when we bring it to focus of our

attention it becomes weak and maybe transforms character. To sense atmospheres we utilize a combination of all our senses and by our physical presence in space we experience the form, volume and dimension of objects (or constellation of objects) in space and all these qualities influences the manner in which we experience the atmospheres of space which for example affect our behavior [16]. As atmospheres are indeterminate above all as regards their ontological status we are not sure whether we should attribute them to the objects or environments from which they proceed or to the people who experience them [1]. However, atmospheres are affected both by people being present in it, and by the surrounding space. Alongside with sociality; materiality, light, color, sound and odor are some of the well-known parameters that transform the qualities of space and as such the atmospheres. The German philosopher Gernot Böhme introduces the concept of atmosphere in 1993 [1] as a basic concept for a new aesthetic without having a point of departure in art. Böhme defines atmospheres as "spheres of presence". He neither locates them in the objects that extrude them, nor in the subjects that physically sense them but in between them and in both of them at the same time [1][4]. This notion is in line with aesthetic pragmatism [22] [25] and as pointed out by Dalsgaard et al [4] there is a lack of dimensions in Böhme's subject-space relation. Turning to the field of HCI it is not sufficient to define atmospheres as multi-sensorial experiences and qualities inherent in an environmental setting as the subjects relation to atmospheric interaction also encompasses a situated action and experience in temporal, social and technological relations [ibid].

2.3 Different approaches to spatiality

According to the notion of atmosphere the relation between space and bodies emphasizes that a phenomenological approach has much to offer the design of pervasive environments [9]. The current concept of space is approached differently within HCI and in order to embrace atmospheres, the concept of space must be grounded in the body. Böhme present two concepts of space as "space as medium of representation" and "space of bodily presence" [2] which forms the basis of the following:

In European thinking the concept of "space" is often thought of in two mathematical ways: one, origination from the Aristotelian understanding of "topos": a place constituted by the relations that cannot be measured and opposed to this; the notion of "spatium" where distances and intervals can be measured as the tradition of Decartes [3][4]. These two distinctions have a profound comparability with the notions of space and place, being introduced by to the field of interaction design by Harrison and Dourish [12][4]. Where "space" denotes geometrical arrangements, that enable certain forms of movement and interaction, "place" evolves as real people fill the space with meaning, practices and interaction. Hence, space is the opportunity, place is the (understood) reality [12]. Yet the notion of our cultural background, which strongly influences our behavior and values and as such our felt

experience of space, is missing here but articulated in Yi-Fu Tuan distinction between space and place[26]. In order to investigate the notion of atmosphere, Böhme emphasize that we need to approach the concept of space as “Space of Bodily Presence” taking a phenomenological approach of being physically situated in the world: *“Bodily space is the manner in which I myself am here and am aware of what is other than me, it is the space of actions, moods and perceptions”*. This notion is in line with the insights claimed by [5] [9] appreciating the centrality of our bodily engagement in spaces within human-computer interaction.

MIDDLE GROUND EXPERIENCE

In this paper the concept of middle ground experience is presented as our bodily experience of spaces embedded with technologies. Middle ground experience specifically points towards understanding how atmospheres mediate our felt experience of a social world. The claim of this paper is, that middle ground experience is missing in the distinction of designing computational artifacts and interfaces to either foreground focus or background awareness [14][15][30]. This dichotomy is insufficient as it neglects our embodied perception and actions in our relation to the physical and socio-cultural world. Middle ground experience is registered in a continuum ranging from foreground focus through middle ground experience to background awareness. The continuum comprises the seamless transitions between the different states of awareness, as we constantly mediate impressions through our senses and bodily motor skills. The notion of middle ground experience is yet unarticulated within the field of interaction design and rests to a large extent upon the concepts of embodied interaction [7] and kinesthetic interaction [10] that term how we experience the world through our embodied actions and in line with McCullough’s notion of “embodied predispositions” [19] and [5] who state the importance of designing interactive technologies for bodily engagement in space. Building upon [10] the middle ground experience conditions the manner in which we experience the world in framing our embodied perception and actions by providing a sense of spatiality in our relation to the physical, social and cultural world.

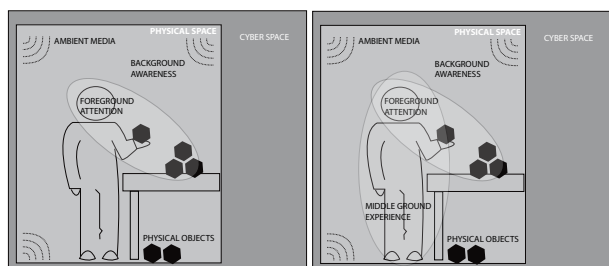


Figure 1 Left; Ishii et al.’s notion of spatial awareness as presented in [29] Right; same model illustrating middle ground experience

To position the argument of the paper, Ishii et al.’s model on background awareness, see figure 1, left, is discussed in the perspective of the middle ground experience, see figure 1, right, emphasizing how form, volume and materiality of the table and physical objects affect the bodily experience of space. Ishii et al [30] accentuate the relation between foreground attention and background awareness as: *“Subtle, background ambient displays are meant to co-exist with, and complement, foreground tasks. Also, background displays can be moved into foreground, and vice versa. Users control this through their personal state of awareness and sometimes, through physical controls”*[30:6].

The relation between foreground attention and background awareness is opposed, yet transitional to each other, as illustrated in the left side of figure 2. Instead of a belief in mental models that successfully steer our actions in the world, we need to approach the design of interactive products from the understanding of the world springs from our bodily engagement with it [5]. We need to address human beings as sensing bodies in a complex world and not just subjects gifted with consciousness and self-consciousness [4].

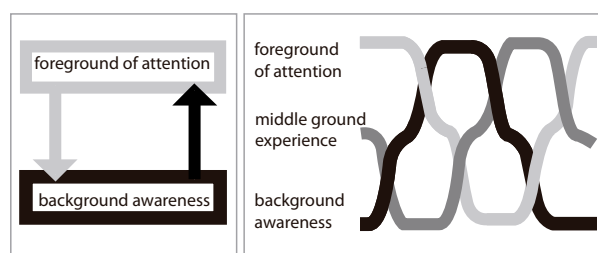


Figure 2 Left; Illustration of Ishii et al.’s notion of the relation between foreground and background [30] Right; “The threads of experience” understood as seamless transitions between foreground, middle ground and background awareness.

In the right-hand side of figure 2, the dichotomy of foreground and background awareness is expanded to encompass middle ground experience and the relation between them are seen as dynamic transitions. The dynamics between them is approached as journey from one state of awareness to another. All these journeys, or “threads of experiences” are woven into the fabric of atmosphere and it forms the bases of our daily life. Hence, several threads of experiences are present simultaneously and the seamless transitions from one state to another characterize our being in the world. The privilege of the foreground is that only one activity occupies it, whereas several activities exist as middle ground experiences and background awareness’s at the same time. Let’s give an example; “Maria is reading a book sitting in her sofa. The text is foreground of attention, her sitting- position, holding the book is middle ground experience. Other sensuous inputs as the texture of the book and the temperature of the room are also middle ground experience. The surrounding space, the living room where she is sitting and the

apartment as such is in her background awareness. The rainy weather outside the window is also background awareness. When Marias mobile suddenly starts ringing, her awareness changes. The sound of ringing becomes foreground of attention and the text she just read differs into background awareness. When she gets up, the middle ground experience changes according to her bodily motor-skills. She reaches her mobile and accepts the call from a good friend. The conversation is now in foreground of attention, and standing next to the table is middle ground experience. While she talks, she notice the increasingly bad weather outside the window, the background awareness has turned through foreground, and then middle ground, as she realizes, that she feels cold. While she is having a convivial chat, Maria walks back to the sofa and wraps herself in a rug. This influences her focus of attention till she again is settled in the sofa, purring some tea and enjoying the cozy atmosphere while chatting with her friend”.

As illustrated in the scenario Marias middle-ground activities are made more or less conscious. Our acting in the world is constantly mediated by what Merleau-Ponty refers to as *praktagnosia*, a “motor-memory” which includes motor skills and the kinesthetic memory of performing them [10]. An example of this can be fingering in playing a musical instrument, in which the use of the fingers and hands are fitted to the players physical abilities as well as characteristics of the instrument [5]. Our bodily experience of the world is however not just a developed skills as Tuan emphasizes: *“A rich an deeply structured background of environmental patterns exist not only in the individual but also in the culture and the spices”* [26 p28]. According to Merleau-Ponty human subjects are primary engaged in answering a motor question with a motor response by searching through a catalogue of movement memories or gestural routines [10]. As such, the motor memory is both composed naturally and culturally appropriated motor skills guiding our actions in the world [ibid]. The perspective of socio-cultural values is also highly relevant to the notion of atmospheres but left unarticulated by Böhme. As agued by [4] the notion of

socio-cultural values expand Böhmes notion of atmosphere, but seems sufficient as we carry with us a repertoire of knowledge from earlier experiences, as well as expectations and anticipations of what we are about to experience, into our encounter with atmospheres is space [ibid]

Arguably, the spectrum between focus of attention and peripheral awareness is lacking and an attempting discussion occurs in accordance with Heidegger’s philosophical notion of readiness at hand / present at hand [27] and whether his distinction has been dominating the dichotomy of designing to foreground and background spaces. According to Heidegger’s philosophy humans do not focus on the tool or the equipment that there are using; but on the work in which they are engaged. While writing we do not draw attention to the pen or keyboard, but to the text. He states, that only when a tool breaks down, it demands attention and what he denotes as “referential structures” e.g. the material of the tool appears only when the tool brakes down. Hence, the Heideggerian notion of foreground attention is opposed to the referential structures, understood as the background.

CASE: Color the Atmosphere

“Color the Atmosphere” is an initial exploration of how technology can be used to create settings where people actively and playfully engage in the creation of atmospheres in domestic environments. An interdisciplinary team consisting of designers, architects, programmers and computer scientists in 2009-10 develops the concept and functional prototype “Color the Atmosphere” which in the following is introduced and discussed with an emphasis to foreground focus, middle ground experience and background awareness.

Design concept

We have designed a space where we on the basis of colors, images and music can make atmosphere transformations. The system is designed to transform current information on a smart phone differently on the stereo, lighting, wall screen, picture frame and screen. The concept draws upon

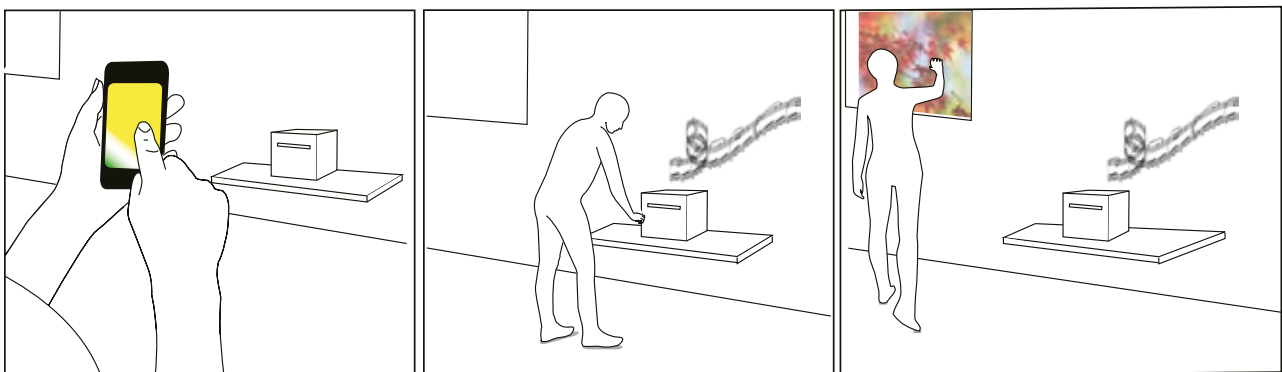


Figure 3: The design set-up: Exploring the concept of creating atmospheres through media transformations in a living room. Through explicit interaction, the gesture of “daubing” yellow color on the stereo turns it into classical music and on the wall yellow appears naturalistic images.

an analogy of coloring space by using *paintbrush*, *palette* and *canvas*. Through the gesture of daubing color on each of the *canvas* surfaces the expression of space transforms according to the *paint* being used. “Color the Atmosphere” is, however, not committed to color transformations but explores the concept of atmospheres by embracing different modes of expression. If you pick a color e.g. *yellow* it determines different outcome according to what kind of media interface it is applied to and every piece of interface respond to *yellow* in its own idiom, see figure 4. It refers to the exploration of hidden layers. How does *yellow* express itself being a pattern? And what does *yellow* sound like? The transformation is done individually, which means that you can also do fights about that *yellow* mean. It aims to be a language by which we can articulate atmospheres in the making, as all media interfaces can be used to challenge the character of the atmospheres. The current set-up consists of smart phone with a RFID tag hidden underneath a cover. Next to each of the media interfaces a plexiglass box is placed hosting both a RFID reader and a touch sensor. Two different ways of manipulating the system is made possible by adding information to the media interface using smart phone or to erase current information by touch. To be more specific, the reader registers the RFID tag when the smart phone is hold near the plexiglass box. The current information is then uploaded to a server, responding by giving feedback on the linked media interface being next to the RFID reader.

Some informed design choices

The following section discusses how the design team approached to make operational our knowledge of creating atmospheres. During the design process several experiments formed our investigation of how to interact with the system in a meaningful way. Whereas traditional brainstorming technique exclude perceptual motor skills, we ascertain video prototyping [18] and video brainstorming [ibid] to be useful methods as it give latitude to explore bodily experience of space in the manner of; how does it feel to be standing here, while the wall corresponds my gesture? Some informed design choices were useful guidelines in the design process and are in the following shortly introduced:

Physical anchoring

To be able to investigate bodily experience of space one of our design constraints was physical anchoring in space and as such a very explicit interaction. We draw upon the notion of how we traditionally strive to accommodate a certain atmosphere by addressing kinesthetic perception. The RFID technology was useful to physically anchor digital media interfaces in space.

Freedom of interaction

We encourage a playful approach to the exploration of atmospheres through five different media interfaces that allow for creativity and fluctuations in expressions. A matrix helped us to link the medias, see figure 4, in the

current set-up referring to stereotypes e.g. linking jazz with smoky animations and pictures of New York. According to the fact that each individual may interpret the expressiveness differently we emphasize the importance of letting the users create their own matrix. The flexibility of the system offers users a myriad of ways to achieve a certain atmosphere and is in line with the concept of “Freedom of interaction”[29].

Controllability

We have investigated the relation between users and system, in the manner of control. We tested how it felt when media spread “in ever-widening circles” when the user just approached one media, like when the user adds color to stereo other media interfaces would slowly follow by turning into the same idiom. As this would give the user a lack in control we finally chose to approach atmospheres being in full control with the media emphasizing lucid feedback between input and output.

Some research challenges

To approach the notion of atmospheres as design constraint one need to be aware that the nature of it relies on different circumstances all very much related to a specific place, specific people and a specific situation. The designer will never be able give an exact prescription of the atmosphere as it is constituted not only by the subjects or the objects but also in the relation between subjects and objects [1]. “Color the Atmosphere” revealed a range of challenges according to design concerns and design heuristics and has indeed suffered the initial hardships of designing atmospheres. The following paragraphs present a clarification emphasizing how the notion of foreground, middle ground and background are valuable to articulate the difficult aspects of designing atmospheres.

Design concerns

The most prominent notions of designing atmospheres through interactive technology ranges from the means of technologies to the paradox of designing for the background awareness and in line with this; how the increased user involvement challenges the notion of atmospheres.

Constituting atmospheres through digital media

When we approach the design of atmospheres we should not consider the senses as separated impressions but rather emphasize that they work interdependently of each other to form a consistent experience. Technologies as means of changing atmospheres have different qualities according to input and output. As input, the utilization of multi-modal senses has gained increasingly significance in the HCI context and they are capable of sensing everything from how loud one can yell or how we squeeze and object [16]. As output technology can also produce different outputs, but in practice light and sound play significant roles in the creation of atmospheres, as they are able to bring about changes instantly [16]. The imbalance of designing for the

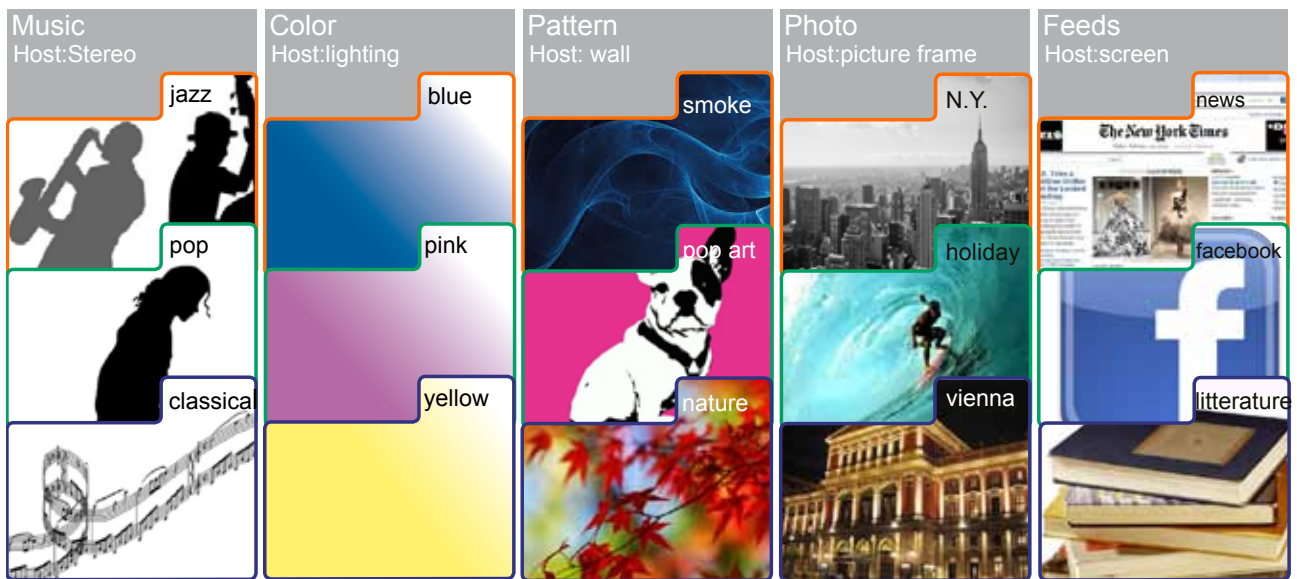


Figure 4 illustrate an extract of the matrix, which forms the basis of the prototype. Here, 3 rows are shown and seven rows are left out according to the limited space. Whereas the rows e.g. the orange illustrate how the media interfaces correspond to each other, the columns denotes the different shapes a media interface can take.

senses is addresses by Pallasmaa, who sees vision and hearing as our sociable senses; whereas others are considered addressing merely private functions being suppressed by the code of culture [21]. In the current design case we did not succeed in embracing more senses, than visual and hearing; although we were flirted with the tactile sense for quite a while. To encompass all senses through technology at the same time (or at least vision, hearing, smell and touch) it should be articulated as design constraint according to the complexity of it.

The paradox of designing for background aesthetics

The claim is, that the main challenge of designing atmospheres within interaction design is the dynamic relation between foreground of attention middle ground experience and background awareness, as it constantly influences on each other and as such the atmospheric experience. To give an example; imagine the situation where somebody tells a great joke. People are laughing and the atmosphere is convivial. As soon as somebody says, “Aren’t we having fun?” the uplifting atmosphere changes. An atmosphere cannot be put into foreground of attention without changing character. The journey between foreground, middle ground and background is an essential design parameter, as we constantly make adjustments in the foreground, and then leaves it into middle ground or background awareness. This dynamics between the different kinds of awareness influences both the design process and user experience and we have to acknowledge this to be able to design for atmospheres.

Atmospheres and user involvement

Drawing upon the established traditions of architecture [31] and performance art [8], designing atmospheres within

interaction design distinguishes in the manner of user involvement. Arguably, traditional scenography and interaction design approach the creation of atmospheres from each end of a spectrum. The following quote made by Fischer-Lichte [ibid] clarify how atmospheres is approached as a background aesthetic within theater:

“The atmosphere comes from the general impression and it becomes part of what influences the perception of the audience through out the performance. Thus in theater productions they usually form calculated parts of the productions”[ibid,p114-115][16].

The interaction designer is however not concerned with staged productions but with the activity of using of technology whereas the foreground attention and middle ground experience play central roles whereas the atmosphere lives in the journey between foreground attention, middle ground experience and background awareness. Further, we have to also acknowledge, that more atmospheres exist side by side: think of a football match, where the players on each team will have different experiences of the atmosphere. The audience will have another experience. All through they all have the ball in focus of attention, their middle ground experience and background awareness are different. To encompass all humans being involved in an atmosphere in interactive environment, the notion of “user” may instead approached this as spect-ators [16] as it embraces both the passive observer and an active participator taking action in a situation. The term comprises not only the extremes of passive and active but also the continuum in between. When we experience interactive systems in spaces with other people, we cannot be active all the time, sometimes we “only” look at other people being “users” in the traditional sense [16,p110]

Design heuristic

“Color the Atmosphere” exists in a constructed living room at the Interactive Spaces lab. The set-up has only to a limited degree been tested on users, whereas a design heuristic is presented emphasizing how user tests should be approached in future set-ups.

Stuck between design rationale and feeling

The general response to the design concept, linking the expressions of different media interfaces, turned out to be “difficult to understand”. This points to the fact that focus of attention overshadows background awareness. And as the foreground also affects our background awareness (e.g. frustration) this is important notion according to atmosphere. When the users of the system seek for explanation it can be questioned whether they are concerned with either the idea of constituting atmospheres using existing media as both input and output; or if they are concerned with the actual design of the system; where the feed-forward and feedback of the system is unclear [29].

It takes time!

To be able to evaluate atmospheric experiences in future set-ups we acknowledge, that the system both has to be experienced in foreground, middle ground and background of awareness. In our initial user tests, the setup was tested for about 20 minutes, which is insufficient according to atmospheric experiences, as the constructing means dominated their focus of attention. We propose that the set-up is tested over a longer period of time, and preferably in home environments. This would embrace how the user approach the set-up in daily life due to the factors of e.g. different social settings, mood changes and motivation. Another perspective we may consider for future tests is that users define the matrix themselves in order to acknowledge the linking between the medias. This could demystify the surprising and overwhelming jumps from one state to another.

Keep the atmosphere unarticulated while testing

We acknowledge, that users should not articulate atmospheric qualities while they are in the middle of testing as the atmosphere changes character when it is forced into foreground of attention. Drawing upon the notions of performance art where *atmospheres are the general impression that influences the perception through out a performance* [8,p.114-115] users should instead be interviewed after testing the set-up and reflect upon their general impression of the atmosphere.

Discussion

The design case has demonstrated the central design concerns and research challenges underlying atmospheres. It is argued, that the notions of foreground, middle ground and background awareness are essential according to both designing and articulating atmospheres within the field of interaction design. Admittedly, the design case has suffered

the initial hardships; it has however, been fruitful according to articulate some of the difficulties of designing atmospheres. On the face of our approach “Color the Atmosphere” dissociates itself from other research projects [23][24] within the field of interaction design by acknowledging two essential qualities of atmospheres; first of all the importance of the bodily experience in space, middle ground, which is illustrated in the gesture of daubing *color* on each of the interior media surfaces, by physically moving around space. Other projects [23][24] neglect the bodily approach by sculpting atmospheres through stationary interfaces. Secondly, the constitution of atmosphere is not understood as predefined scenery like e.g. festive atmosphere [24] but approaches with respect the its mutable qualities and designed with a large degree of adaptability.

To advance middle ground experience further a discussion is raised according to the data-centered approach to background awareness and this being opposed to a bodily motor-centered approach. Admittedly the two different aims of technology do not eliminate each other, but they represent two different traditions within HCI. When Ishii et al.[14] are designing for background awareness, the space serves for carriers or control of virtual data as in AmbientROOM [ibid] and the purpose of the informational data is placed above all regards [ibid]. Although they use classical means for affecting the atmosphere e.g. sounds from the rainforest, the focus is not on the perceptible body, but how to increase the information load. As argued in the paper the concept of middle ground experience the efficiency-focused technologies may no longer suffice and need to be complemented by knowledge on the aesthetic aspects of user experience [5]. Drawing upon aesthetics of interaction [22] we should seek to affect all senses in the way we interact with technology [ibid]. By these comments the attention must be directed toward what is valuable for future work as the notion of atmosphere gives a nuanced view on interaction design.

CONCLUSION AND FUTURE WORKS:

Broadening the concept of spatial technologies to embrace the philosophical notion on atmospheres, the importance of bodily awareness in space is pinpointed and presented as middle ground spaces into the dichotomy of foreground-background spaces. The notion of middle ground experience conditions the manner in which we experience the world in framing our embodied perception and actions by providing a sense of spatiality in our relation to the physical, social and cultural world. Through a design case, explicit interactions investigate how we *Articulate Atmospheres through Middle Ground Experiences in Interaction Design*. The case revealed a range of design concerns and design heuristic according to user experience. The most prominent concerns points at the paradox between foreground attention and background awareness – as an atmospheres most likely changes character when it dragged into foreground attention. Therefore we claim, that

to atmospheres shall be approached as a journey between foreground focus, middle ground experience and background awareness. As different forms of sensations constantly mediate middle ground experience the temporal concern must be acknowledged. Finally the discussion point towards the notion of middle ground experience emphasizing that the previous data-centered approach to background space is opposed to a perceptible motor-centered approach acknowledging that aesthetic interaction has much to offer middle ground and background aesthetics in the field of interaction design.

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Augmented Bodies - Experiments in Body-centered Design

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ABSTRACT

This paper describes a body-centered interaction design course, the Augmented Body, held at Chalmers University of Technology as a part of the Interaction Design programme. The intention of the course is to explore experience-based interaction design that starts in the human body ‘body-centered design’, as a method for providing alternative interaction forms and metaphors over those driven by technological development. To do this a design research approach was used to explore the course topic, its outcome, and the use that springs out of it. This paper discusses the role of body-centered design within and outside of the course context.

Keywords

Body-centered design, phenomenology, lived body, body extensions, experiment, interaction design

INTRODUCTION

Interaction Design has seen some major trends since establishing as a field and putting embodiment central in design is one of them [5]. More recently, designing with the human body in mind for learning and bodies in motion are examples following this direction [9, 13, 16]. Art using technology has a strong tradition in working with the human body and some recent design examples (Auger + Loizeau [1], Frey [6], Kuwakubo, Tosa [12]) worked as inspiration in this work. Body-centered design making use of a rich notion of human bodies aspires to take this development even further. A central concept in the course is the lived body as proposed in phenomenology, sharing a non-dualistic view on perception [3, 8]. Work on nontraditional Interfaces in the Human-Computer Interaction (HCI) community making extensive use of the human senses [11] also served as inspiration.

Body-centered Design

What is meant by body-centered design is by no means something well-defined. One of the main goals in the course was to start in experience when creating a concept design,

as experience starts in the human body, and doing so inherently as a consequence land in something body-centered. Instead of starting to look at products, with its fixed conceptions, traditions and production methods we looked at ‘body extensions’ putting the body in centre of the action. The idea of starting within the body takes inspiration from the post-Cartesian criticism laying ground for the embodiment trend, although taking its essence with an ambition of pushing it further. Recent years has called for action for new methods addressing the perceived problems raised through this theory.

“we are almost too well used with certain interaction forms that we hardly are able to question or to imagine alternatives. For this reason we need new approaches”... “that open up for new insights and throw away or at least provide alternatives to old interaction paradigms and metaphors.” (Moen 2005)

Experience and presence were major themes in the course opposed to theory and representation. This manifested through exercises in experiencing environments, complementing the theory provided to the students.

Even though we do believe in equal importance of mind and body for interaction experiences [15], highlighting body experience becomes a tool to be able to find alternatives.

THE AUGMENTED BODY

The general organization of the Augmented Body course was that of a brief introduction to related theory and design research touching on different aspects related to the course topic followed by a larger block of group experimentations. Being a rather small project course, half-time eight weeks altogether, the groups were asked to experiment to keep expanding their design space, not working towards commercialized products, but to stop somewhere half-way making their prototypes. Using exaggeration was also encouraged, being a well-tried interaction design method aiding innovation (See e.g. Djajadiningrat et. al [4]).

This was done to be able to provide exaggerated illustrative examples, as common in fashion, highlighting corporal aspects of experience use, and providing alternatives to existing interaction paradigms and metaphors, as called for by Moen [13].

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Figure 1. Augmented bodies – Sound Inductor, Color Caller, the Sixth Vest, and Sonar Cap.

Apart from a general goal of setting up the course as a design research program, producing design examples for explorations and discussion based in an agenda [2], we provided three general project guidelines. Namely to focus on,

1. Use rather than technology.
2. Experience rather than efficiency.
3. Body extensions rather than objects.

This was done to keep the projects within the same design space, keeping the human body in center of the design.

Process

By making the students stop halfway through their design processes, not forcing to adapt to real-world constraints, their minds stayed open to ideas otherwise discarded. The beginning of the course also included workshops focusing on central themes aiding the course goals, such as sketching in hardware [14] and space perception. Tuition of the group projects mainly focused on assisting in adhering to the provided guidelines. The studio environment sat up for the course also provided some selected literature for inspiration [7, 10].

Course outcome

The course attracted 16 students, most of them from the Interaction Design Masters programmes' second year. After initial workshops and experiments they gathered in five groups of three to four participants. The five concept tools developed were the following, Origin – a space recreating a feeling similar to being in a mothers' womb (fig. 3, 5), Sound Inductor – a suit strengthen bodily experience of sound through vibration, Color Caller – a device visualizing colours through smell and audible information for the visually impaired, the Sixth West – a jacket with information visualizations through vibration in a grid arranged on your body (fig. 1), and finally Sonar Cap - a

navigational aid relaying solely on sound output built into a baseball cap (fig. 1 and 4)

The projects all use ubiquitous electronic components such as stepper motors, vibrators, distance sensors, batteries and speakers, and easily available microcontrollers for prototyping user experience. All five projects put focus on the user experience and provided unusual interaction forms with characteristics not typical for IT-products.

Exhibition

The five projects were exhibited in a large exhibition hall to a diverse audience (fig 2). The accessibility of the projects became prominent during the exhibition, as very few visitors argued 'meaning' or 'use' of the works which you may expect with experimental projects like this, reactions were quite the opposite. It was suggested by a visitor that this arena was making both art and technology more accessible; no further research was done however to confirm that assumption.



Figure 2. The exhibition space.



Figure 3. Origin – recreating a feeling similar of being in a mothers' womb.

The fact that the works were presented in a gallery 'test site' may have influenced the visitors open mind approaching the projects, but also the fact that the bodies of the visitors themselves were in focus, and not primary the works of the exhibitors. Most of the visitors took time to try out all of the five projects and also to discuss the projects with their makers.

DISCUSSION

From experiencing the projects in the exhibition it looks like giving less focus on designed objects, through working with body-extensions, less focus was also on the fact that you were actually interacting. Being simple, focused projects, not trying to perform many different tasks at once may have aided this experience.

From the examples in the course we can see that body-centered solutions propose use that may from the interactors' point of view being just as focused as other use of information technology (IT), but from an outside viewpoint being looked upon as being more engaged with the world and not with technology. The aiding interfaces proposed here connects to the here-and-now world in another way, and less to something perceived as abstract or far away. One reason for this may be that they are 'camouflaged' as regular design artefacts, not looking like technological objects.

One major challenge with the experience-based experimental approach, and design program thinking in general, is to find a way back to 'something useful' – a product or service with a functional business model. Although this dilemma may be similar to ones also in other design fields, of adapting grand experimental models to something that finds its way also to the mundane every-day. However, opposed to some design research objects of which intention never were to leave the gallery context, the essentials in the proposed concepts here are bases for possible future commercialized ideas, although probably iterated into something quite different.

The result of the work in the course can be said to be twofold. One part is the actual displayed projects, which in themselves are examples of underlying philosophy and strategy behind them, displaying the ideas behind the course in an implicit way for future students and designers. The second half of the result would be the starting point itself, defined by the guidelines and the proposed design process, which in turn may be altered to investigate other possible results.



Figure 4. Sonar Cap in use.

Future work

Future work may include different ways to alter the starting point – possibly working with multi-user devices or devices with multiple uses, or by including a theme to narrow down the design space further. Another way to approach future development may also be to investigate different ways to take the existing concepts to a market. It would also be interesting to bring this approach, and possibly adapt it, for use also in real-world design cases.

Future approaches to the field would need to be careful about when to create multi-purpose devices, and single-purpose devices adapted to specific tasks and contexts. A challenge would be to balance the possible penetration of a product at one hand, and the adapted bodily experience in the other, still being able to adhering to the philosophy behind the guidelines.

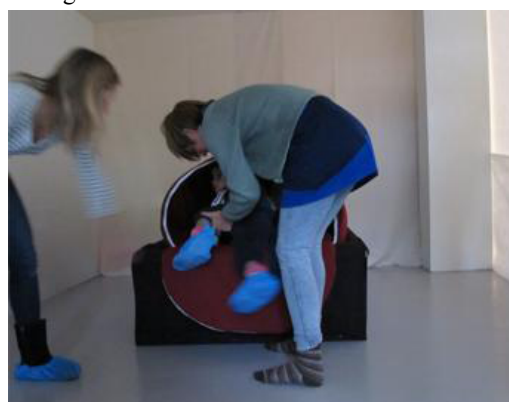


Figure 5. A young user trying out Origin with his mother.

Another more compressed way of making use of the approach would be to use it as an ideation method early in a design process to help get rid of conceptions one might have about how electronic devices should behave and occur.

CONCLUSION

This paper describes an early first try in teaching body-centered experience design making use of body extensions to keep bodily experience central, and the five projects it resulted in. The process applied in the course is by no means the straightforward way to find efficient commercially successful products, but rather for complementing current views on how to perform design of new digital artefacts and what it may result in. It is proposed that we in the course had some success in directing the focus from the designed IT-object and common hand and vision-based IT-use, to creating interactions appearing to occur more in the here-and-now world. From the experiment projects it looks like the body-centered approach has some potential in taking out the 'face' part still predominated in human-computer interface design, being able to provide alternatives to how technology interaction contextually could integrate the world around us.

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Design Process for Interactive Architecture at the @Lab

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ABSTRACT

Ambience 2011 conference explores new interfaces between design and fabrication that are changing the way architects think and make architecture — from parametric design processes and digital fabrication to composites and embedded computing. In this paper, we explore the impact of some of these technologies on the design process — in particular, the process we have been involved in over the past four years in an interdisciplinary collaborative design research environment known as the @Lab, in the city of Halifax on Canada's east coast.

Keywords

Responsive environments, biofeedback, design process

INTRODUCTION

The @Lab is dedicated to design research in electronic textiles at an architectural scale. [1]. The @Lab creates prototype artifacts and environments that combine traditional crafts in fiber arts, printmaking, jewelry and pattern making with electronics and architectural design. The lab is an unusually interdisciplinary team, composed of two principal investigators who are from architecture and textiles, and a design and fabrication team of technicians and designers that includes a computer programmer, a jeweler, a textile technician, and graduate students in mechanical engineering and architecture. We also benefit from the advice and collaboration of senior electrical engineers. [2]

Sarah: Sometimes I wonder what drives me to design and make responsive environments. As an architect,

I was trained to make stable objects that sit securely in space, while sunlight slowly turns around them across a day. But I believe these are not separated. The movement of sun and wind, of people drawn to a warm spot to drink a cup of tea, or drawing a curtain to filter harsh light — these actions show the intrinsic relation between natural cycles and movement in architecture. Over the past few years my interest in movement has expanded to the field of interactive architecture. This is why I created @Lab with Robin Muller [3].

In a multi- and inter-disciplinary team, the design process is both more collaborative and more open ended. Design emerges, often in unexpected ways, from the team interacting with itself. We might even say that the sociological and disciplinary characteristics of the team members become parameters for the emergent design — as much as do the performance objectives or the characteristics of materials. In this sense, steering is a metaphor for the design process — not only in terms of varying material strengths and characteristics or by incorporating responsiveness into architecture — but by allowing forms and materials to emerge from a more open-ended collaborative process involving an interdisciplinary group. Like steering a boat in the waves, the destination is clear but the path is far from straight, requiring continual adjustment. In this paper, we illustrate this design process with two interactive architectural projects and reflect on our steering strategy.

Responsive Stage Set

Sarah: My earlier design work involved tracing the movements of bodies in space to generate fluid forms. This led to a number of ephemeral installations and pavilions derived from dance

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choreography. It seemed inevitable to take the idea of movement into the surface of the structures — so architecture itself would start to move [4].

The project was developed with a commercial partner, the Maria Osende Flamenco Dance Company. The brief was to design and develop a portable backdrop for this touring dance company that performs in widely varying venues and settings. The concept was to visually expand the impact of flamenco by translating its music and singing into visual effects. A second idea was to work with the flamboyant traditional aesthetic of flamenco — its lacy mantillas, elaborate dresses, and dramatic lighting — in the design of the stage set.



Maria Osende performing with the set in its folded position. Photo: Greg Richardson.

This was a parametric design process at many levels. Most fundamentally, it involved a constraint-driven approach to problem solving — it had to collapse completely and be light enough to put on a car rack. It had to be easy to open and close, and offer varying configurations for different dance numbers. It was based on the principle that all parts were set in relation to the whole. And lastly, like much contemporary parametric design, it luxuriated in the capabilities offered by digital design processes, to work with pattern at multiple scales. A trial version in a flamenco dress set the stage for a fuller development in the stage set. Both of these design prototypes aimed to visually enhance

the movement of the dancer and her accompanying musicians, creating a dynamic, responsive trio between dancer, musicians and textile. The research involved integrating smart LEDs and nitinol wire into the textile surfaces, to change fabric configuration and color in real time and in relation to the characteristic wrist movements of the dancer (captured with an accelerometer as a motion sensor) and of a violinist (triggered by pitch and intensity).



Detail of the fabric folded with nitinol wires triggered by the music of the violinist. Photo: Greg Richardson.

Some challenges included addressing the interference of static electricity from the costume in movement on the low-voltage smart LED network, wire connections in very soft and dynamic networks attached to stretch fabrics, utilization of various kinds of nitinol to permit reversible movement, and isolation of musical frequencies to precisely control the actuators. Several findings from this design research were brought into our next project of a warming hut — bringing a responsive environment to a public outdoor space in a Canadian winter.



Maria Osende performing in front of the set in its open position and with all the LED lights on purple. Photo: Greg Richardson

Warming Hut

This project was commissioned by the city of Halifax to be located adjacent to a seasonal skating oval erected on the Halifax Commons for the Canada Winter Games in 2011.

The design brief was to create and erect a durable, reusable shelter that would serve as a place for small groups to gather, out of the wind and weather. To this brief, we added our desire to reflect local culture and employ a modular and lightweight construction system and to include digitally driven machines for manufacturing. The form of the hut is derived from the First Nations teepees erected on this site the previous summer in celebration of the 400th anniversary of the Mi'kmaw Chief Membertou. Reworking the conical form of the traditional teepee into a modern structure able to withstand winter weather, we designed the structure in eight aluminum-framed sections that fit together. Each section is surfaced in fabric and clear lexan polycarbonate shingles to allow light inside.



The warming hut for skaters is erected on the Commons in Halifax Nova Scotia, Canada. Photo: by Greg Richardson

Benches around the hut perimeter were interlaced with seat warmers, bringing warmth directly in contact with the body. One seat — distinguished by woolen hand mitts — is reserved for a special feature, and the focus of the responsive design for this warming hut. This was the human heart. It connects to the heartbeat of the athlete on the skating oval, but it is also a sign of the social and communal experience of sitting with others. Electrical engineer Alan Macy who specializes in biomedical electronics developed the heartbeat amplifier. His design for the HBA registers and amplifies the electrical activity in the human body. We became interested in making these minute internal movements visible and experiential, outside the body. In our collaboration with him, we created an environment that responds in light, color and sound when a person occupies the seat equipped with the heartbeat amplifier, incorporating temporality, responsiveness (and a conversation piece!) into the hut.

To express the beautiful and subtle qualities of the heartbeat, we worked with the HBA's two variable inputs (amplitude and frequency) making one visible and the other audible. Pulsating lights were atomized in a snowflake chandelier made of thousands of fiber-optic strands, while the sound was merely amplified to resonate in the hut.



View from below of the chandelier made of a thousand fabric snow flakes with fiber optics changing color in response to the hear beats. Photo: Greg Richardson



Inside view of the warming hut. Photo: Greg Richardson

Some of the challenges we encountered included protecting the electronics from moisture, heating up the copper plates that registered electric current (so people could touch them in sub-zero weather), making the materials durable enough to resist sticky fingers (gummed up with Beavertail pastries) and a curious public. The reward is people lining up to experience the warming hut and enjoying learning about their body in a way that is entirely theirs.



The contact plates registered the person's electric current in their body and send it to the HBA. These copper plates were heated so people's hands could touch the metal in sub-zero weather and covered with wool pouches to incite the removal of gloves. Photo: Greg Richardson

ACKNOWLEDGMENTS

The Co-PI of the @Lab is Robin Muller, a faculty member of The Textile Division at the Nova Scotia College of Art and Design.

To begin this research we organized a workshop as part of the Acadia conference in October 2007. We want to thank the five experts in electronic textiles for contributing to a publication resulted from this most enriching collaboration.

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Towards Interconnectivity: Appropriation of Responsive Minimum Energy Structures in an Architectural Context

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ABSTRACT

This paper introduces Reef, a design-led investigation into the conceptualization and materialization of a self-actuated ceiling surface. Relying on minimum energy structures as an example of an adaptive element, Reef showcases an approach in which the design of shape-changing structures through an efficient 2D-manufacturing process leads to the creation of highly poetic and complex adaptive structures, while suggesting new opportunities for the implementation of electro-active polymer technologies in a domestic context. By reporting on the conceptualization, the design and realization of the installation Reef, this paper will highlight future possibilities for architectural materialization questioning how responsive technologies can encourage the design of a home more interconnected with its surrounding environment.

Keywords

Smart materials, adaptive minimum energy structure, responsive architecture

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Variable-modulus and Active Material Systems

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ABSTRACT

By understanding and utilizing the capacities and thresholds of advanced materials, the aim of this paper is to propose architectural interfaces that share similarities with the structural and performative aspects of natural systems. Through a two-fold approach, that of passive adaptation and dynamic response the research is aiming at proposing design methodologies based on material properties and organization.

In doing so, it shifts from current and past examples of mechanical approaches of adaptation, towards biological paradigms of seamless material integration. More specifically it looks at composite material systems with variable elastic properties and with embedded sensing and actuation.

The emphasis therefore is not placed on architectural formalism, but on how synthetic environments can be expressed through constant exchanges of energy, matter and information.

Keywords

Responsive, adaptive, material system, shape-changing

BIOLOGICAL PROCESSES OF RESPONSE AND ADAPTATION

Approaching architectural interfaces as systems able to respond and 'communicate' with the ever-changing conditions of their environment shares similarities with the architecture of living organisms:

Natural systems are constantly adapting to changing forces by assembling and disassembling their materials in reaction to changing loads. While the generic formation may be genetically determined, the local adaptability is indeterminate. Such adaptive remodelling is based on the seamless integration of sensing, processing and actuation within one material solution. Systems in nature mainly consist of two types of constituent materials; fibres, which are the reinforcement and withstand tension and the matrix

that bonds them and maintains their relative positions.

The combination and hierarchical structure of the two, yields a vast range of graded structures. The same collagen fibres are used in low-modulus highly extensible structures such as blood vessels, intermediate-modulus tissues such as tendons and high modulus rigid materials such as bone [4].

Differentiation in moduli is a phenomenon that can be met in one and same structure allowing variations in their mechanical properties. Bone is a distinctive example of such a system; it is a natural composite of collagen fibres reinforced with a calcium matrix, whose mechanical properties vary locally. It acquires diverse shapes in relation to its particular function within the organism while its internal constitution alters in stiffness and porosity allowing through this diversity a multiplicity of functions to take place—from buckling and bending prevention to blood and nutrients flow allowance. Furthermore, the embedded sensors (osteocytes) and actuators (osteoblasts and osteoclasts) allow the performance of a constant remodelling cycle. Osteoblasts are the bone forming cells, while osteoclasts remove material in under stressed areas where the material is not needed.

These internal sensing and actuating mechanisms are termed homeostatic mechanisms and they are related to the capacity of the system to maintain its steadiness and overall identity even when there is undergoing disturbance. Thus, variable modulus modelling can be examined as part of a homeostatic process, which defines the adaptation, and dynamic response of the proposed system as part of its niche -the domain of interaction of its components.

The composition of natural materials and the principles governing tissue architecture can become a viable input in the production of architectural material systems of non-linear elasticity.

Material deposition, material chemistry, movement, and modulus-variability, aspects that this research is dealing with in an effort of proposing alternative dynamic architectures are all interrelated, triggered by mechanisms of adaptive growth. However, when one tries to incorporate biological processes into architecture, s/he needs to be aware of the differences between natural and artificial systems. Natural systems possess certain properties that are not met in their artificial structures: they have the ability to

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self-repair, to self-organise and overall to be autonomous while being open to energy exchange. There is a pronounced difference in their chemistry and there is no equivalent artificial material (except certain self-healing ones) capable of performing self-adaptation and self-repair. Biological materials and structures are not static, but systems that actively respond to the biophysical stimuli of their environment. During growth they are able to adapt their architecture to the improving of their functionality according to external constraints. Later on they are again capable of adaptive response to occurring changes in the environment [5].

ARCHITECTURAL PROCESSES OF ADAPTATION

The aim of this research is to present an approach of coupling passive and dynamic materials together in search of passive adaptation and dynamic response. Polymers of different hardness and elasticity are able to contribute to the passive response of the system and its structural integrity, while smart shape changing materials on the microclimatic modulation of the system as well as its spatiotemporal reconfigurations.

In achieving material variability within a continuous composite system, the current research aims at utilizing computational simulations of shape optimization. This process, which has been described as a “digital simulation of biological adaptive growth”, creates a pattern along a structurally analysed system, exhibiting ranges of stress concentrations [7]. The stress concentrations are related to the range of material needed when specific loads are being applied and act as homeostatic agents towards structural equilibrium. The interpretation of the stress diagram can change according to the design objectives: It can lead to subtraction of building material, or to a gradient differentiation of material densities, hardness or mechanical directional properties (with the addition of fibres) in a similar to nature’s way. However, this process can only take place as a dynamic simulation, leaving a stable structure, as a final product.

High-performance composite materials can be distributed along a surface, forming its skeleton, which although not able to act dynamically, its chemistry and formation encompasses certain structural objectives as well as forming the ‘skeleton’ of the spatial articulation.

Computational tools hence, acquire an integral role in design by establishing a feedback loop between generation and analysis in search of coherent configurations within the range of multipurpose parameters. An entire catalogue of input data and responses can be created able to display the possible changes in performance to be achieved. Accordingly it can assist in selecting the appropriate solution for existing environmental data.

RESPONSE THROUGH MATERIALITY

While the mechanical adaptability stems from a passive solution –after being in a dynamic reconfiguration within the digital realm-, there are advanced materials with dynamic responsive attributes which can be distributed

locally along a structure and provide it with interactive performative capacities.

Material technology has advanced greatly over recent years and the so-called smart materials are now readily available in the market. Smart materials have integral sensorial and actuation capacities and they respond to different stimuli ranging from temperature differentials, to electric and magnetic currents, or to UV light. Their response can be linked to shape change (Shape Memory Materials), colour change (thermochromic, photochromic), change in thickness (magnetorheological), energy change (piezoelectrics), etc. Although the main scale of application of smart materials is that of nano-technologies, their recent usage in aerospace and automotive industry may prove to give fruitful insights for application in the construction industry.

The main types of materials that this research is aiming at is exploring further the potential applications shape memory and colour changing materials on architectural interfaces.

Shape memory materials are characterized by their ability to undergo phase transition without losing their physical state when an input of thermal energy or electrical current acts on them. This is achieved through a two state molecular re-arrangement: a relatively soft and deformable state (martensite) and a more rigid one (the austenite). The two states, which can be pre-set by the designer, will define the multiple shape changes in-between, related to direct temperature differentials. The material can bend and straighten, twist and untwist (nitinol alloys), contract and expand (flexinol alloys). They can be designed to have an actuation temperature of 30 degrees Celsius, a temperature easily achieved through direct solar contact. Shape Memory Alloys are commonly produced in the form of wire, sheet, ribbon or tube.

Another category of SMM is the Shape Memory Polymers (SMP). They are more recent than SMAs and have several advantages over the alloys, providing larger deformation, ease of processing, shape stability and flexibility. Like SMAs, these polymeric smart materials have the ability to return from a deformed state (temporary shape) to their original (permanent) shape induced by an external stimulus (trigger), which is the temperature change. However, unlike SMAs there are no smart polymers in the market yet capable of a two-way reversible phase transformation to temperature differentials. This means that a plastic deformation from an external source is necessitated when in low temperature.

Thermochromic and thermotropic materials react to thermal energy by changing their colour or optical characteristics (opacity), respectively. They can be mixed to moulding or casting materials for different applications and their activation can be engineered to accurate temperatures ranging from -15°C to 70°C.

Thermochromic and thermotropic polymers can be utilised for adaptive solar protection due to their autonomous control of daylight; this can lead to a noticeable reduction of heat during the summer months. The self-regulation of thermotropic materials offers the possibility of passively switching systems without any additional electrical supply and therefore leads to decrease of energy consumption. The solar energy itself becomes the operator and enhances the energy efficiency and sufficiency of buildings. Thermochromic materials on the other hand, can only change colour. However, the alteration of colour from darker to lighter or vice versa offers the potential of differential heat absorption inside the building.

Both of those materials can be applicable to any surface and their response relates to the basic matrix with which they are mixed. The scope of this research is to identify the advantages and outcomes of mixing thermosensitive materials with different polymeric matrices as well as finding new applications in architecture.

Photochromic materials have similar characteristics to thermochromic; having the ability to change various shades, colour intensity or even optical attributes, by responding to UV light. Their application can mainly relate to indication of energy states and surface temperatures. Therefore, surfaces with embedded photosensitive response could be utilised on ground surface articulations indicating hotter and colder places and consequently inform programmatic activities.

Responsiveness through material integration entails the provision of unforeseen attributes to a structure, ranging from climatic comfort, spatial flexibility, noise occlusion and functional plurality. Smart material structures are capable of exhibiting direct, immediate and local response to activating stimuli, obtaining a phenotypically gradient phase-change due to local pressure differentials. The latter as well as new haptic qualities stemming from the polymers they are embedded in, add to the new aesthetics that material intelligent systems can promote.

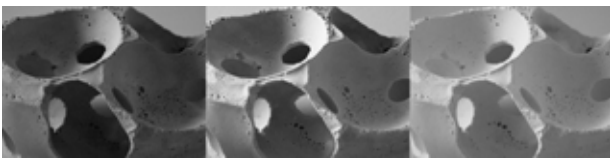


Figure 01: thermochromic pigments impregnated into plaster. When heat acts on the material, the colour is changing from the colour of the pigments (black) to the colour of the base material (white).

Mechanical vs biological

Coupling natural mechanisms with smart and high-performance materials can enable us to develop coherent architectural systems, “which rather than being based on external mechanical elements are triggered by the material's own properties, leading to integral design solutions with eventually higher degrees of responsiveness” [1].

Smart materials have the potential of becoming fully integrated into composite material structures and thus retaining the seamlessness and continuity of the whole system, minimizing the different components that a conventional structure would need. The morphological continuity that such a structure entails is “of such a nature that the system as a whole cannot be fully understood simply by analysing its components. This is usually referred to as emergent properties” [3].

While mechanical systems consist of distinct elements such as sensors, processors, microcontrollers and actuating units, smart materials with embedded responsive properties comprise holistic systems. Their intelligence is integrated in their microstructure. The first example defines non-autonomous systems whose “components are produced by processes, independent of their organization and their operation” [6], while in the proposed example the components are integral to the system and cannot be abstracted without the system losing its identity.

DESIGN STUDIES

The study initiates by exploring the combination of polymer composites and shape-changing materials. In the first set of experiments the material thresholds that were taken into consideration were the ones stemming from a composite system consisting of silicon with attached shape memory alloys. The silicon's hardness was low, in order to allow deformation when the alloys were applied. In technical terms *Shore hardness* is related to the elastic modulus of the material. The Shore A scale (ranging between 10-40 units) is used for 'softer' rubbers while the Shore D scale (between 90-120) is used for 'harder' ones.

Anisotropic attributes and their ability to add either stiffness or alter the direction of deformation, is one more parameter that has partially been explored. This adds to the complexity of the system by tailoring its mechanical properties according to specific anticipated performative behaviours. They have the ability to enhance the stiffness and tension properties, to introduce torsional behaviour, and to tailor the transparency levels of the composite.

Mediating Surface

The idea of dynamic composite components, comprised by SMAs and polymers was further explored through the design of a ‘mediating surface’. At the material level the additional parameter was the increase of the number of the hardness of the polymeric parts along the surface. Each level of hardness corresponds to the different functionalities of the surface, varying from structural core to the elastic kinetic membranes with the embedded alloys. The performance and behaviour of the alloys are only evaluated when embedded in flexible polymers. Different polymers are being tested according to their flexibility and their bonding to the alloys.

The overall surface although continuous and locally flexible is also structurally stable. In terms of performance the surface –after careful analysis and calibration of material shape change- can act as thermal barrier, or

facilitate natural ventilation. The surface is perceived not as a static boundary of demarcation, but as a dynamic transient zone of energy flow. The response is thereby the result of the synergy between energy and material processed information while the ambient temperature can be visualized by the transient phase change.

The utilization of SMPs at a later stage, proved to have several advantages over that of the alloys, providing larger deformation, ease of initial transformation, shape stability, and better bonding with the polymeric framework.

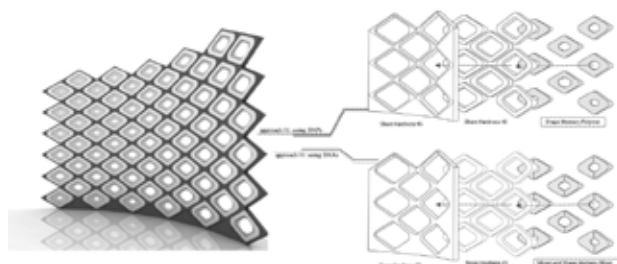


Figure 02: Illustration of mediating surface. The porosity is changing according to ambient temperature.

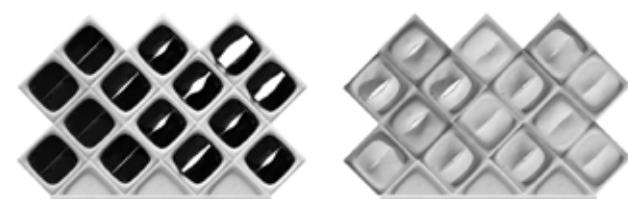


Figure 03: Illustration of surface, by arraying different physical models of components. On the left: Tile made by using resin and Shape Memory Polymers and, on the right: Tile made by using resin and Silicon with Embedded Shape Memory Alloys.

Mediating shell

The idea of the mediating surface is currently being developed as part of a pavilion design. The pavilion is envisaged as a shell structure able to respond through its global morphology, orientation and structure to environmental pressures and spatial articulation as well as to dynamically adapt to changing conditions with the addition of responsive materials.

The formation of the pavilion originates from digital studies on funicular shells, whose graded curvature corresponds to stress concentrations. The selection of funicular structures (minimal surfaces) as an initial study is strongly related with the ease of fabrication of composite shells and with the better understanding of the force flow distribution along the surface since the curvature levels correspond directly to the highest stress concentration.

Topological transformations of the original geometry together with fluid dynamics analysis, illustrate the best possible orientation in relation to wind patterns for the avoidance of severe turbulence. Moreover it shows where negative pressure occurs which is associated with the

porosity articulation along the surface and the distribution of lighter materials.

In its first stage the pavilion abstracted from a particular site, acts as a showcase of different materials and responsive properties. It also demonstrates potential design methodologies that incorporate physics dynamics, material properties, and environmental analysis in relation to form and material distribution.

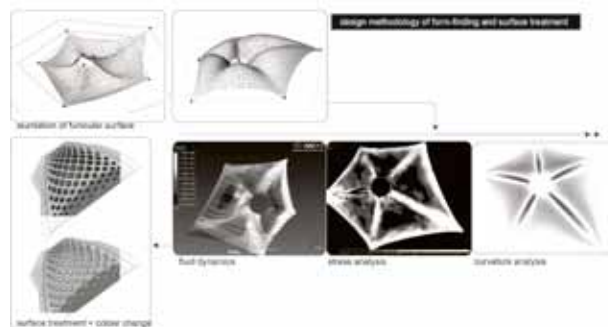


Figure 04: Design methodology for form-finding and surface treatment. A series of analysis exhibit best orientation, stress concentrations and curvature for optimum material distribution.

Fabrication techniques

In terms of fabrication, fibre lay up and vacuum forming for the main structure together with injection moulding for the polymeric components might prove to be the most appropriate techniques. An intriguing technique, that is not yet plausible in large-scale structures, is the application of selective deposition modelling of polymers with different hardness.

CONCLUSIONS

Material advancements present an opportunity to rethink architecture as part of its environment. Likewise natural systems where properties change through a seamless material deposition, the focus is not on the articulation of disparate elements but on continuous material systems that through their intrinsic properties can demonstrate both a *stable adaptation* towards structural integrity as well as exhibit *dynamic response* to extrinsic stimuli. The hypothesis is that materiality can become the driving force of morphogenetic processes “from within the materials rather than being imposed from the outside to an inert matter” [2].

With the affordance of composite materials that resemble the mechanical properties of natural ones, the use of new fabrication techniques and the possibility of integrating materials with responsive attributes, buildings can come closer to the idea of a living organism and to function as autonomous systems open to information (energies) from the environment.

From a cybernetic point of view, the material systems described in this paper are only single-valued, meaning that their transformations lead to single outputs, related to either shape-change or colour-change. If certain properties were

to be coupled, the system would potentially respond to more stimuli and consequently the outputs would be proliferated. The aim thereafter is to define such feedback relations between structures, environment and users that can yield better interconnectivity among them and could promote more resilient environments.

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Textiles: Alternative Forms of Malleability

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ABSTRACT

The simulation of textile behavior remains a difficult computational problem, often eliminating the nuanced and nonlinear behavior that contributes to the character of a given textile and its response to deformation through buckling, creasing, and wrinkling. Historically these types of behavior have been extricated from the discipline of architectural form, because of their unpredictability and lack of control in the design process. The reverse is true of craft and textiles, where material variability is a vital form of expression, form and identity. This paper will examine how digital tools in conjunction with textiles are posing new alternatives for form and expression. This paper will examine the authors' research using analog textile models in the development of ceramic furniture prototypes. Digital tools are used in parallel with the textiles as a means to examine form finding, geometric variation, and plasticity, in the development of structural volumes and surfaces. Methods for reinserting the textile models into the digital workflow, their management in the digital environment using subdivision surface software, and prototyping are discussed.

Keywords

analog, ceramic, computation, digital, nonlinear, form finding, malleability, membrane, model, plasticity, prototyping, subdivision surface software, textile, craft.

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An Interactive Textile Hanging: Textile, Spaces and Interaction

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ABSTRACT

This paper presents three scenarios in which we explore different possibilities for interactive textile hangings. We have identified a series of variables that address the relationship between the expressions of the textile pattern and the pattern created by the rotating motors. We use these variables combined with classic contextual dichotomies to discuss the relationship between the textile expression, the temporal expression, the place and the interactions for these scenarios.

Keywords

Textile design, interactive textiles, moving textile surfaces, wall hangings

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Wearable Technologies: from Performativity to Materiality

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ABSTRACT

The terms performance and performativity have garnered an increased importance in the field of visual and media arts, humanities and the technosciences, signaling an epistemological shift from representational to performative modes of knowledge and experience production. This paper traces the terms performance and performativity—historically and conceptually—within the broad fields of performance (linguistics, sociology, anthropology, theatre, dance, music and performance art) to extend their meaning(s) to the fields of technoscience and wearables. This paper aims to posit that a coupling of wearables technology and performativity: 1) is not only crucial to an understanding of the materiality of the wearable object and its social practice, but also 2) offers new grounds for a repositioning of research within the fields of wearables and performance.

Keywords

Wearables, performance, performativity, materiality, human/nonhuman, technoscience

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Alternative Representation of Fashion to the Catwalk and Photographic Imaging

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ABSTRACT

Though the world of fashion both attracts and engages in performance and spectacle it is often fleeting. Nevertheless, this satisfies the restless world of the *fashionistas* with their constant hunger for the 'next best thing'...

In the autumn of 2009, the British Fashion Council at Somerset House, London hosted the exhibition SHOWstudio FASHION REVOLUTION. A decade earlier, British photographer Nick Knight sought to 'liberate' the photograph from the static flat pages of the magazine, through the launch of the website SHOWstudio. He saw that the evolution of web technology could allow capture of the garment via the Net, and the resultant Fashion Film revolution would significantly change how fashion is viewed:

By its very nature of-the-moment, fashion has found its natural counterpart in the speed and immediacy of the Web. This pace, coupled with the demand (necessity, even) to see clothing in motion, makes the Internet the perfect medium for fashion film. [6]

Ten years on, SHOWstudio's exhibition explored that new ground.

This research proposes further challenge to the use of moving image in developing ideas about fashion discipline representation. It questions the origins and motivation of one male designer using clothes as a means of creative practice to examine personal history and memory:

...but clothes are at best the alter ego and also in part mask and distort the primal sense of the physical self. [4]

The views of psychologist Stanley Hall (1844-1924), writing on 'Some Aspects of the Early Sense of Self' are challenging when reflecting on children's investment in the relationship and experiences they have with clothing. The 'double' or 'shadow' is the translation or meaning of the term *alter ego*, and the notion of 'double' comes to mind when I track by memory when I began to look in the long white mirror of my grandmother's home at a clothed persona, that other *me* on the other side. My growth – not uncommonly – was one of self-identification in this way, that of the 'double' in the mirror. The 'shadow' in fashion terminology is the silhouette, and the quality of that outline or that dense, black, flat two-dimensional shape is the recognisable hallmark of 'good fashion'. So, referencing Stanley, the mirror, the double, the shadow, the silhouette, and the mask shape and distort the *primal* sense one may have of *the self*. And, extending this, arguably a life's journey may be spent playing with narratives of the possibilities of self through means of dress.

Keywords

Fashion, Touch, Memory, Video

CONTEXT

Most fashion designers are committed to producing a collection twice a year for the market, which takes the shape of one Spring-Summer and one Autumn-Winter collection. These garment collections are then presented to the designers' audience, through public Fashion shows initially, then to buyers in showrooms. It is in the showrooms that orders are placed by department stores and boutiques from around the world and here where business begins for the designers. Therefore the focus of designers is

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to initially captivate a large audience that will lead to a greater number of buyers of their garments. Invited press contributes to the diffusion of the brand through show reports online, in newspapers and in fashion magazines around the world. Photographers and stylists immortalize designer garments in fashion stories programmed months in advance for the glossy magazines, as the film *The September Issue* by R. J. Cutler, 2009 confirms. The film documents the production of *Vogue America's* 2007 September fall fashion issue. The marketing of fashion is a potent machine, competitive, costly and exciting.

Fashion shows were first seen in department stores as early as 1910 in Wanamaker's Department store in Philadelphia, and in the London store Selfridges as late as the 1930s. In Italy the first collections shown to an International public were in the early post-war years of the 1950s to a mainly American clientele as described in Malossi and Vergani's book *La Sala Bianca, Nascita Della Moda Italiana* (1992). The Fashion show is what we collectively associate with Fashion, and the mode of presentation therefore most favored by designers to communicate with their audience. The fashion designer, who works closely with the show producer on sets, conceptualizes the shows and the choreography of the models' movements along a catwalk set to music.

Since the early years shows have evolved considerably and today are highly polished productions, with lavish money spent on the latest technology and collaborators to create the spectacles they have become. The journalist Deyan Sudjic recalls a 2001 fashion show in Milan, Italy:

Tadao Ando, has done nothing less than create the fashion world's equivalent of a grandiloquent Victorian opera house. It's a place designed for celebrities to disgorge from their limousines, to promenade along what feels like a triumphal route on their way to their reserved seats...The reception desks could pass for art too, immaculate, precise, glass boxes illuminated from within as if they were by Dan Flavin. [7]

It is argued that designers have moved away from the convention of the catwalk in the 21st century and have chosen the language of performance and installation art as a means of reaching their audiences. Hussein Chalayan, who had an original interest in the discipline of architecture, exemplifies such work. Chalayan maintains that he creates *objects for the body*, which allows him to break away from the rules of dress. It permits the designer to work more abstractly, whereby the moving body is the vehicle for ideas. The solo exhibition *From Fashion and Back* at the Design Museum, London in 2009 showed fine examples of his work, many demonstrating this principle. Some fashion designers have taken their concern with

spectacle further, where through the exposition of the garment in a particular setting, the designer works metaphorically to 'prick and cut through the skin of the viewer', and thereby unsettle them. The garment fades and the designer connects with the emotions of the viewer with the total theatre approach. The viewer is drawn into the enchanted world created by the designer, and is mesmerized by it.

The late Alexander McQueen is described as the designer who dared to take his audience to the very edge of fashion where the discourse became no longer the length of skirts that season, the question of whether prints are in or out, and what colours we are all to be wearing. His messages were raw and authentic, delivered with sound impeccable tailoring, and an understanding of cloth and cut, tricking the soft centres of an audience often perceived as comprising mere 'fluffy followers of fashion'. McQueen's quiet unassuming persona delivered 'deadly blows' to the fashion world and to the greater public beyond. In *Alexander McQueen Savage Beauty* by Andrew Bolton (2011), we are given insight into the thinking behind the designer in his own words. In his recollection of the fashion show VOSS spring/summer 2001 McQueen describes:

(In this collection) the idea was to turn people's faces on themselves. I wanted to turn it around and make them think, am I actually as good as what I am looking at? [2]

The guests were seated around a mirrored case, and forced to look at their own reflections. Habitually comfortable in their role to pass judgment on the beauty and appropriateness of the designer's collection, suddenly the focus is on them, which results in a disturbance of the 'natural' audience/spectacle relationship. Without knowing the show has already begun by the fact of their presence, the audience participants are left to look at themselves for a few minutes before the models enter stage right.

The models too do not see the usual audience they confidently perform to, and only see themselves as the light goes up inside the box where they stand. The body language of the models becomes uncertain, subtle, and introspective in nature. The rules of engagement change. The audience now switches to observation of these vulnerable and fragile creatures through a glass case.

McQueen comments further:

The show was staged inside a huge two-way mirrored box, whereby the audience was reflected in the glass before the show began and then the models could not see out once the show started.

These beautiful models were walking around in the room, and then suddenly this woman who wouldn't be considered beautiful was revealed. It was about trying to trap something that wasn't conventionally beautiful to show that beauty comes from within. [2]

This poignant commentary by McQueen challenges - from the inside - the superficial world of fashion and perceptions of what beauty is or might be. The way the show was conceived and choreographed by McQueen in 2001 obliges both the models and the audience to look inwardly. He also throws light on the role of the fashion designer in contemporary culture, and whether there is space for the designer to also be considered artist. Evidence shows the fashion designers' role is not only to respond to the functional lifestyle needs of the end consumer. Fashion has always lain between the necessity to design for function, and the value of creating an escape from the real *self* through distortion, or shaping and re-enforcing aspirations. This responds to the human desire of the primal need to belong.

I initially decided to reflect on the practice of fashion from designer to creator of spectacle, and to dissect that practice into distinct areas of investigation:

- The creative process of design - looking at the various stages of development, from research, design development, pattern cutting and manufacture;
- The human figure – the human figure is central to the design considerations in fashion. Observing the body in movement, in its static state, fragments of the body in isolation, the power of the physical gesture;
- The setting - spatial awareness and the body placed in a given context. The setting is instrumental in the creation of atmosphere. The importance of place and non-place, and what that evokes in terms of tension and imagination. Parallels can be drawn here also with sound and non-sound (or silence);
- Sound – this can also evoke a theme and jog the memory of feelings, experiences, places. Dialogues that comment on people and what they wear.

MEMORY

The work has evolved from considering my own position in my practice as a fashion designer, with 25 years experience in the international domain designing across diverse realities within the discipline. In all cases I have been heavily involved in the production of catwalk shows and the presentation of high end products to a global audience.

The world of fashion has a tag, and that is of the superficial, and the transitory. This tag has not been and never was the reason for my journey. A personal diary begins to retrace my steps.

I make reference here to the Scots Professor of Poetry, Kenneth White, and specifically to his text discussed by McIntosh in writing about White's work in the publication *Soil and Soul*, where White comments on the reclaiming of the land of the Scottish island of Egg by its inhabitants from the Laird of his own estate:

I am suggesting that we try and get back an earth-sense, a ground sense, and a freshness of the world. [5]

The 'ground sense' Professor White makes reference to, of authenticity and a sense of place, has driven me to look at what led me to design for the body. The personal connection I have with the language of dress caused me to delve back into personal memory, moments of personal history, which have triggered the association that I have with cloth and clothing today. By writing on my memories of childhood I have been able to qualify my *being* as a fashion designer.

The experience and the evaluation of dressing and fashioning have existed in my state of *being-in* since I can remember. There is a language of materials and form that have haunted me through time. The notions of touch and the memory of this as a child have contributed in driving the concepts in my practice-based research. Our worlds are shaped by our experiences, and, as William Blattner explains, we are already familiar with our own perceptions of the world as we see it.

Commentary by Blattner on Heidegger's *Being and Time* (2009), reveals the following:

He (Heidegger) argues that our fundamental experience of the world is one of familiarity. We do not normally experience ourselves as subjects standing over against an object, but rather as at home in a world we already understand. [1]

My parents were performing Opera singers, my grandfather too, and my grandmother was a pianist. Each had huge impact on my formative years in the UK.

My father would be in his black concert suit with bow tie, white starched collar and shirt. My mother poised with beautifully made up eyes, shimmered with sparkle and sumptuous gowns. At the theatre in costume, after the Opera, my parents would receive us in their dressing rooms. They would greet us with open

arms amongst the colours and textures of costume and sets, with wildly painted faces crafted confidently, by exaggerated gestures with chalk stick in hand: a post-performance treat for me as a child doused with electric energy, stuff of magic.

With busy parents and weekends spent performing, the wonders of my childhood were spent with my maternal grandmother.

Dancing in the backyard at her home in the evening light. Watching and helping Nanna cook in the school holidays, listening to her tales of War and the personal toll it took. Cooking would often entail the ritual of preparing pastry as part of that process. As she would tell the stories the children would huddle around the cool smooth table surface of pale blue Formica, where she would start the preparation, so much lard, so much flour. With the raising of the flour dust, like magic as the pastry was turned her voice and words would resonate in my head. I looked forward to those stories of real life; they were full of aspiration, danger and adventure. The excitement was the wonder with anticipation of an adult world ahead.

Loss

Rituals were sacred as if like performances themselves. I recall taking in turns to sit at the piano with her. Listening to the sounds the instrument would make I sat transfixed observing how she lightly drew her hands across the familiar keyboard, full of emotion as she connected with the shiny, smooth black lacquered and ivory keys. The sweet melody of her favorite piece, the Blue Danube by Johann Strauss II would fill the air. Her long fingers would caress the keys like one would human skin. She had an intimacy with that piano that only love can tell. This is the story of the poetry of loss, black trees.

SLOW MOTION

I have aimed to slow down the process of engagement with the clothed body in order to appreciate the nuances normally lost in the speed of fashion catwalks, film or music video. Personal stories of cloth and clothing are often intimate and sacred, made of the ritual of dressing alone. My interest in slow motion video technique was prompted by the desire to engage with a contemplative and meditative aesthetic, shared by video artists like Bill Viola.

The enchantment of that pace and intention arguably runs counter to the fleeting performance and urgent spectacle more typical of SHOWstudio.

Exploratory research activity collated material on how artists have used a range of visual media to narrate human nature where memory, loss, living and desire to believe in the infinite are key propelling factors. Often, artists' responses to these themes are emotional or visceral, rather than primarily intellectual. In works by Bausch, Sugimoto and Viola there is a 'jolt' taking the viewer into a form of meditative mode, deliberately stripping out critical capacity in confrontation with an alternative non-cerebral essence. The gallery environment and installation conventions define particularly with whom and how audience engagement happens, and this presents an alternative place and mediation to that of the catwalk.

Viola comments on tears and water as clear symbols in his video narratives. He works with intimacy to make it public and draws in crowds to watch with amazement the wonders of human emotion as universal experience. Viola's trick is with time, and by slowing down images he captures the poetry in motion, human emotion. In *Dolorosa* (2000) the viewer participates in the slowly unfolding pain of the figure in the portrait as it moves. The video technique is precise in taking us back through our own memories of grief, life and death. As I watch I am drawn back to moments of my own grief for the passing of loved ones, and the slow-motion techniques mastered by Viola are overwhelming. I am drawn to the work and engage with it, not for its beauty, but for the emotion it triggers within my own memories. This is affective work, which touches all notions of the world of endings and beginning, your world, my world and a collective world. Viola works simply with the complexities of human nature.

STOP

In 2004, drawn to water, I stood in front of seascapes, where life held still for me in that moment. These were photographs at the Serpentine Gallery London, exhibited by the artist Hiroshi Sugimoto. The stillness and 'emptiness' of those images were charged with content. The horizon, a constant horizontal line, had been photographed in different locations around the world. How is one able to describe the atmosphere? It holds an intangible beauty where the viewer is not quite observing reality. The work lies liminal, it is *between* as if in our dreams, where definite shapes and forms are absent. But in the black and white print there is an unsettling beauty with not quite a true view of the horizon. The sea looks deep and intimidating in the foreground. Though there is a calm within the images, which unites the series. The viewer, transfixed, can expect a change of events at any time. The balance or tension is what keeps the viewer's attention.

TOUCH

Other memories I hold include Sunday church, where as a child I would sing in the choir and be watched by Nanna from the gallery.

The scent of musk would prevail from the vestry wardrobes as we opened them and scrambled hurriedly for our gowns. The weekly exercise of donning the soft ample red robes that then contrasted with the dressing of the starched white collar and the pristine white surplice to match, was something I looked forward too.

On some occasions in the church gallery with my grandmother, I would relish the moment in the service where the vicar would face his congregation, and signify the commencement of the Sermon.

This would be the moment where I would sit and lean against her fur coat and begin my journey of dreaming fantastically, whilst brushing my cheek against the hairs of the coat. At the same time I would inhale the sweet scent of face powder, the dust of which must have travelled through the air whilst she applied it to her face that morning. It must have travelled along the long hairs to the very depths of her fur coat. I would also brush my fingers along those hairs and enjoy the tingling sensation across my fingertips.

Although we are told that the sense of touch exists all over our bodies, whereas other senses reside in specific locations, we are in many ways less sensitized to touch and its powers as a communicating tool.

The radio broadcaster Peter White, who is visually impaired, describes touch:

I can only touch one tiny bit at a time; although I can spread hands across a figure, in reality, if I want to examine it properly, I have to trace it with my finger. [8]

The sensation and acute sensitivity of the fingertips that White references, resonates with my own experiences. In the caress is the moment in which the tips of the fingers are charged with meaning by the object in question, triggered by sensations that induce the imagination, the familiar and memory. The touch is the qualifying act of that which we see. Cloth and the touching of it brings to my mind place and memory. This was and it is today the starting point for my engagement with Fashion.

Prompted by the reflective text I had been writing, I began to work with flour dust by directly making forms with it. I followed the same rituals experienced as a child. I mixed flour dust and water to make the dough. The sensation of the cold flour between my fingers and the manipulation of the dough-like folds of skin led me to shape hands and limbs with expressive gestures. I then transferred the same principles to earth clay and evolved white forms with the body in mind, which I pieced together and reconfigured, making a photographic record of my compositions. The outcomes were cinematic in quality as a result of design decisions made as regards their lighting. The white porcelain placed on a matt black background was affected by shadows, suggestive of film nostalgia. The body parts suggested balletic poses.

The video work *Touch* (2007/II) by Zlatko and Rachel Cosic is a small art piece, sensitive to on-going themes within my own research of the human body and nature in close proximity. Zlatko and Cosic are quiet in their message. Like the seascapes of Sugimoto, they have filmed water from differing sources, from waterfalls to the oceans of the world, to then superimpose them onto intimate studies of the body in movement. To the contemplative sound of the sea we engage with the gestures and *touch* the fragmented bodies as they perform. There is an inability to read bones and flesh into the visual representation, with its messages of transparency and ever-changing surface qualities. The audience witnesses a dream space: memories share this same space where visual images are fluid, they come into the frame of our thinking, and in a moment are gone.

The non-corporal, invisible element of our body's water is the protagonist in this piece, and the body itself is the mere silhouette or shadow. As the soul in love is invisible so is water. This considerable component part of our body mass then soaks away or evaporates into air when our souls have departed. Zlatko and Cosic's corporeal mortality is expressed through grains of sand, detected when the body moves, an overture to our own materiality returning and merging with the earth. I am interested in the tension these ambiguities set up for the viewer. What also makes the work interesting is that it too is situated between disciplines. Fake and luminescent in character, the flat *love narrative* suggests etched glass, print and illustration as well as film.

SELF

The subject of my work prior to this research was the female figure. I worked with performers in the capacity as art director. But the role of the filmmaker and the discourse of the voyeur and the male gaze are challenging concepts, and I took the decision to work with self as subject in the video footage of my research.

Initially I found that the rejection of one set of difficult criteria presented another set. Myself as subject promised self-conscious reaction and inhibition. But the work of Pina Bausch shows that a performer with no experience of dance and movement technique can convey extraordinary core emotion with the clothed body in movement.

Bausch, not unlike Viola, has had a profound influence on our perception and understanding of the human condition through dance theatre and the work of her company Tanztheater Wuppertal. Bausch's role and interpretive capacity, with such a fragile frame in *Café Muller* (1978), is breath-taking. The rhythmic gestures of desperation intensify along the thread of the sole female mezzo-soprano voice uttering the words, 'when I am lain, when I am lain in earth' from Purcell's *Dido and Aeneas*. The piece is constructed on the memory of Bausch's own parents running a café, and the colourful clients who paid it visits. It is a piece primarily dealing with the layers of human condition and ultimately loss. The *pas de trios*, a dance with two shadows, shows the dancer engaged with the symbols of death through her own shadows, the prelude to her own end (Pina died rapidly through liver cancer in 2010).

Bausch does not hold back and 'electrocutes' the seated audiences into seeing and believing the truth about life through her total theatre.

In *Rite of Spring* (1975), Bausch worked in 'raw' fashion by directing fast, dramatic and emotional dancers who battled with one another and the earth they were rooted in to avoid sacrifice. This is a primeval trance to haunting music. Unlike the quiet message of Zlatko and Cosic, these balletic performers battle the ritual out in increasingly torrid earth to the climatic strings of Stravinsky. The audience is caught up in the progressive deterioration and exhaustion of the dancers. Bausch stuns the spectators with this brutal tale. What makes her work truly incisive is the decision to tell the tale, beyond the restraints and control of classical dance. The resources are then found from within the body in movement, the voice in sound and the working through of emotions to convey those innermost answers she seeks in a language and formula that works and touches all.

MOVING

I moved into working with the screen and moving image. Consequent research objectives have then been to discover an unexpected knowledge within garments and their wearer, through a process of memory exposition and via use of particular filmic language methods – cut, focus, edit, fade and return, dissolve, etc. Through this practice-based research frame, I have endeavoured to challenge what fashion film might be beyond a veneer of painted faces and trend induced fashions.

I attempted to find locations that would induce

contemplation, in similar ways to the seascapes of Sugimoto. Though some interesting examples were produced, many logistical factors were involved in making within this genre. I also found immediate difficulty in simultaneously 'performing' and directing the camera operator.

Returning to initial ideas, it was important to keep the language contained and simple. Nostalgia and the silver screen were complimentary to the mood of memory and loss. I worked with themes of black, white and silver. A secondary light source from an adjacent room, warm and soft, provoked another mood, and the combination of these elements resulted in a series of shadow studies, creating intimate observations of the body through movement. Dark, soft and bodily, they imply texture and a sense of cloth, but are at the same time abstract and minimal, suggesting emotional motion, alluding to landscape and earth itself.

Signal Box, Herzog & de Meuron (1998), photographed by Sugimoto, is clearly out of focus, and deliberately so. The dust-like resultant quality of this work is unusual. The materiality of the photographic subject intensifies, and what one expects to be solid form is soft. The photographic technique interferes with our vision, setting us in a dreamlike trance: we might almost reach out and touch the building itself.

Sugimoto deconstructs from the existing and recognizable subjects of photographic composition. He slowly pulls out of focus the images, just enough for the viewer still to recognize the subjects. When we are in a dream state the images we visualize are more than often not defined and all the edges are blurred, not unlike *Signal Box*.

I have operated oppositionally to this: when the viewer stands in front of my work there is a clear need to construct the references as the footage rolls and the subject can be glimpsed, recognized and formed.

The work I was generating began to move closer to my own sensibility of memory. I was finding solace in the way I had been able to see other artists find language to do so. The *Shadows, melting* [3], as Sugimoto terms it, and the textured space it moved across became my focus. The pieces began to embody emotional charge.

COLOUR

Derek Jarman's eclectic practice as filmmaker, artist, set designer, writer and political activist culminated in his struggle against the loss of his eyesight in the latter stages of his terminal illness. This is unfolded through his story of colours in his book, *Chroma* (1995) in which he offered lucid notes and reflections about colour with acute knowledge and observation and the awareness of the imminent loss of that experience.

I share his appreciation of the Renaissance, its art and players recorded in history: earth, paint, pigment, dust, fresco colours of renaissance painting. I knew the theatre and its opulence as a child through *Opera* and my subsequent years spent in Florence, Italy. The paintings of the time have theatrical overtones with exaggerated gesture and expression from the actors in the sacred scenes, distilled with rich colour hues. Jarman captured this intensity in his films, *Caravaggio* (1985), *The Madness of King George* (1995) and others, and *Chroma* qualified his understanding of colour language as soaked in the deep past of collective memories, with references that span the historical, emotional and mythical.

I chose to work with colour.

Fabric fibres absorb colour dye in different ways, silk, wool, cashmere. The intensity, or saturation of colour in a fabric catches my eye and I am drawn into it. My hand reaches out to make contact with it, it moves and we begin to dance. The light works its way over the surface and a medley of nuances of that colour are played to me and we dance a little more. Volume is suggested as I reach out my hand beyond and behind the fabric to take full control, and the fabric fills out. I liken this experience to jumping into the blue of a swimming pool. Seduced by the light that sparkles on the water and the lure of blue. The colour intensifies as the basin gets deeper and the subtle swaying of the water itself, takes me to the waters edge. I jump, and as I cut through the shiny surface a sensual rush goes through my body. Each part of me makes contact with that water, until it has enveloped my body, dressed with it, I am at one. With the same token, the painterly brushing of the beauticians cold cream on my face, and the coolness of aired, starched cotton felt against the skin in my ritual of dressing, draw me back through fashion to the deepness of blue.

Working with different coloured garments and lighting, recognising colour as key to my own fashion design work, I sought to test composition and affect in relation to my 'self', the 'double' in the mirror, the 'shadow' stored in my memory, brought back to life in new ways through pungent expression. Results were unexpected, capturing the dynamic and power of colour itself, highlighting the sensuality and importance of texture:

Tripping firstly the camera out of focus, I moved myself into the field of vision and the lens would repeatedly seek to adjust and capture the colour resulting in the colour

shifting at different rates across the screen as my body moved. In total silence as if in meditation, I would move and contort my body responding to the behaviour of the colour as I was observing it on the screen. At times rapid explosive changes of mood would take place or slow bleeding from one hue to another. Suddenly the work was taking on its own spirit and identity. It immediately appeared the work could sit as well as in the bodily, somewhere beyond fashion, between video, painting, materials.

CONCLUSION

I sought to pull *image*, the fashion body, apart through the use of film, mixing performance, lens focus, and editing to achieve this. Progressively, through development the body, *my body*, has become less important as the subject of the video. The camera and light have taken primacy, and subsequently the work has successfully acquired its 'own identity' and form. It is bodily as it shows evidence of a form rotating, contracting and expanding within a given time frame; it is material as the powdered qualities and broken surface transmit this; it is painting as one sees colour as if thrown across the canvas in emotional gesture; it is illustrative as one catches glimpses of the stylised body parts. I look again beyond that mirrored surface and am at moments reconciled with the *other me*, a clothed persona on the other side.

This research through theorised practice has allowed investigation of the medium of film and video to assert an alternative to 'fast fashion film' and thereby develop a personal creative voice and a subjective informed viewpoint as an experienced fashion designer. This voice and viewpoint is captured in film format through the final body of work as a discipline practitioner expressive alternative to 'fashionista convention'. Less confined by *image*, in fashion terms, this alternative perspective is tied to experience, memory and emotions, and thereby to the *subject* rather than the *object* of fashion film. The research has permitted me to deconstruct the language of fashion: fabric, colour, the body in movement and its representation on film, and I have become enabled to more clearly observe the body as an 'ideas vehicle' within the realms of illustration, painting and video space.

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