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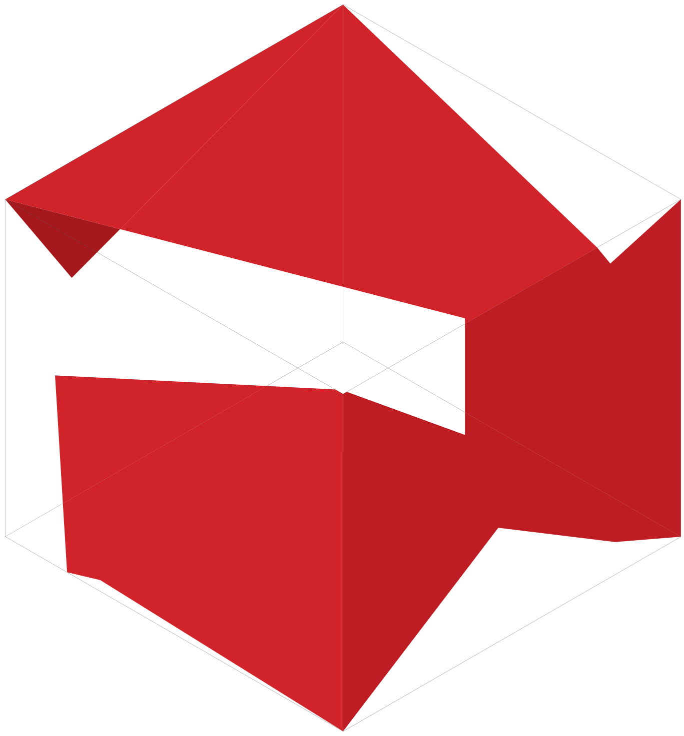

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Listener:
A Probe Into Information Based Material Specification

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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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Listener: a probe into information based material specification

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Introduction

Digital fabrication has introduced a new material nearness in architectural practice. If architecture as a design practice always incorporates the intention of materialisation, the material understanding present in traditional architectural drawing relies on the diagrammatic notations that are in turn interpreted by the builder-craftsman. As the interfaces between design and fabrication mature they introduce a new sense of material thinking into architectural practice. Here, the scope of architectural drawing changes from the representational to the instructional, directly informing the cutting, milling or printing of materials. The implications of this technological change are two-fold. On the one hand, it introduces a new performative understanding of materials. As designers engage with unprecedented levels of material control, detail and complexity, the design of material behaviour becomes part of the architectural remit. This leads, on the other hand, to a new understanding of materials as variegated and responsive to the particular design criteria of their implementation. If industrialisation allowed the standardisation of materials, and therefore a safe prediction of their structural performance, the era of digital fabrication allows a further detailing of this performative understanding allowing for the thinking of new graded materials that shift in their performance becoming stronger, lighter or more flexible in response to their implementation.

Figure 1. The *Listener* prototype.

To fully exploit these technological advances it is important to develop models by which performative and variegated material designs can become part of an architecture design practice. This paper presents the interdisciplinary design project *Listener*. The project is developed as collaboration between architecture and textile design and speculates on how traditions for textile specification and fabrication can inform architectural production. The project further queries the performative thinking of materials. Merging the computationally steered with the structurally performing, *Listener* is the design of a complex and multi-layered membrane. By combining advances in intelligent textiles with parametric modelling we devised our own bespoke interfaces that link standard architectural design environments (Rhino and Grasshopper), CNC knitting machine (Stoll) and simple computational steering (Arduino).

Textiles as Models for Material Specification

The *Listener* project explores textile design as a model for material specification in architecture. By developing a bespoke composite that brings together multiple fibre types each with their own material performance, our aim is to develop an architectural textile designed in response to a set of performance requirements. *Listener* makes use of textile techniques for material production. Textile techniques are the means by which single fibres are brought together to form unified materials. As a knowledge field, textile design is concerned with how single fibres can be brought together to create the necessary performances of strength, flexibility or aesthetics required.

Working at the scale of the stitch, the course or the loop, textiles are highly defined surfaces (Braddock & O'Mahony, 1999). By controlling the individual intertwining of the fibres the performance of the material can be controlled. The material performance is further defined by the quality and performance of the fibres by which the material is made. In the process of textile fabrication, specific fibres can be substituted with others, thereby changing the quality and performance of the material. This ability to continually change the quality of the material allows the thinking of textiles as graded materials. Hyper-specified and designed, these materials are developed in response to particular criteria by which the strength, elasticity or density of a material can be devised.

As in building culture, where the traditional handcrafts enable a high level of material control, the industrialisation of textile manufacturing effected a standardisation of production (Anderson, 1992). With the event of new computer-controlled technologies, textile production can return to a practice of hyper-specification. Since the mid 70s machine control and computationally steered pattern design were introduced to the textile industry. The interfacing with computational design environments allows the designer to develop the material stitch by stitch, directing the structural and material composition. Creating direct links between the space of design and the space of fabrication, the idea of the hyper-specified materials are seen as bespoke composites, differentiated and graded, and whose particular detailing is a central part of a projects overall solution.

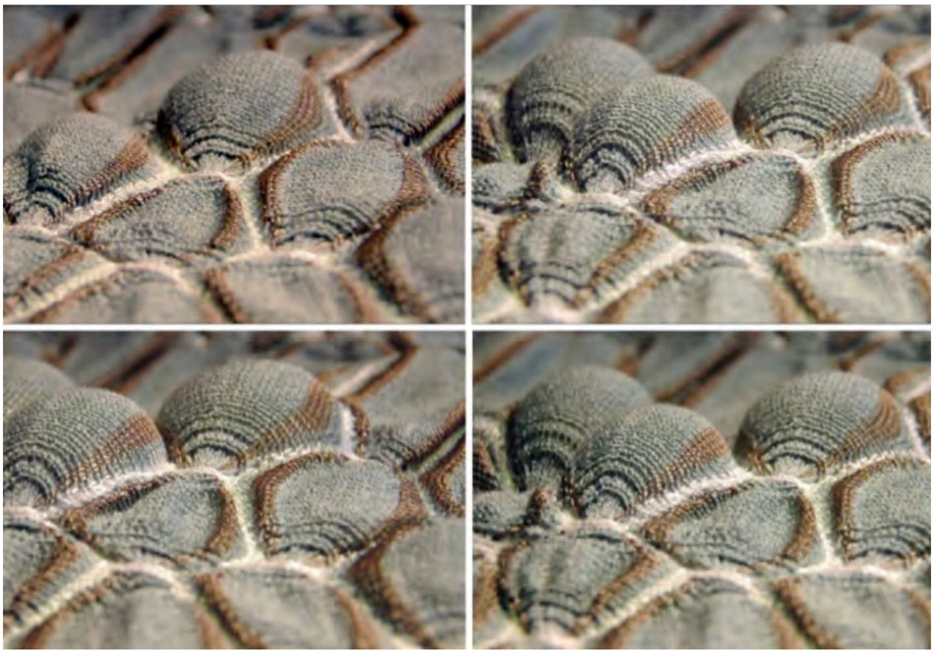

Figure 2. Inflating the air chambers.

It is this knowledge that can be successfully transferred to an architectural field of study. In architecture the idea of composite materials is fundamental. Modern building culture is defined by ever more complex composites designed in response to the different design criteria of aesthetics, function and building code. The context for the *Listener* project is to ask how the design of bespoke composites can become part of architectural design process.

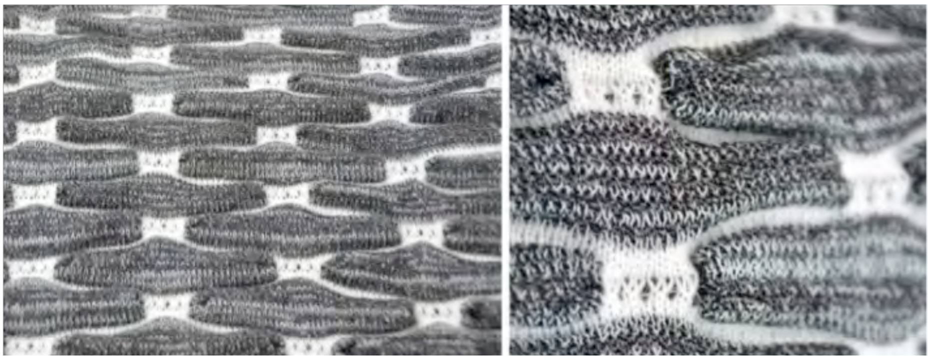

Figure 3. Geometrical and material variation.

This material thinking has precedence in architectural practice at a very different scale. In contemporary building practice the idea of bespoke elements and the distribution of individualised building components have led to new methods for variegation to allow for formal freedom or structural differentiation. A particular example of this practice can be seen in the design development of the CCTV tower by OMA in Beijing. This project clearly exemplifies the way in which parameters, in this case structural, become criteria for informing a specified material distribution. Here, the design team developed complex patterns to optimise the perimeter steel and steel reinforced concrete columns. Working in close collaboration with the OMA design team, ARUP developed unfolded two dimensional computer models by which to develop a rationalisation of the structural skin making it stronger around the moment of counter-levering for the horizontal arch. Working from a base bracing pattern the design team found ways of variegating the pattern in response to load simulations. This process was highly performative: "[t]he structure is highly indeterminate, so changing the bracing pattern resulted in a new distribution of forces within the columns, braces, and edge-beams. … Patterning became an extremely involved iterative process" (Caroll, et al, 2005). The team developed unfolded stress patterns by which to communicate between the design teams. The resulting patterns and their splayed logic have much in common with textile patterns and the performative material thinking present in textile design.

In *Listener,* the aim is to find ways of interfacing this material thinking directly with production. Using advanced CNC-based knitting as a technological platform, the project develops parametric patterns that are non-repetitive and bespoke in order to specify the material.

Developing the Listener Prototype

Listener is developed as a prototype by which the concepts, design and technologies of material specification can be examined. As a working model, *Listener* acts as a full-scale testing piece that, in its design and development, goes through all phases of implementation thereby allowing the assessment of feasibility, creative troubleshooting and problem-solving through design iteration.

Figure 4. Testing double sided textile structure.

Listener is designed to a particular programme scenario. *Listener* is imagined as a bed-spread that 'listens' to the bedside murmurings of its sleepers and responds with its own soft rhythms. This design scenario allows us to formulate design criteria, scale and its responsive behaviour. In *Listener* the idea of the performative is understood both as a structural principle as well as means of incorporating computationally steered events. As a research project *Listener* is understood as an exploratory probe prototyping the involved technologies. Understood as a robotic membrane (Ramsgard Thomsen, 2008), *Listener* integrates conductive and resistive fibres. The fibres act as sensors that are used as a network of capacity sensors inlaid in the membrane. These in turn trigger a series of air chambers integrated into the surface. As the occupant touches the surface, the network of sensors detects the location of this impact and inflates the surface accordingly. *Listener* is an active surface intermittently inflating and deflating in response to its occupation; listening to its environment and reacting to its change.

As a hyper-specified surface *Listener* develops parametric tools by which to design and develop the surface as non-repetitive graded material. In developing the textile pattern and material specification for *Listener* we needed to develop means of creating three-dimensional bulges to inlay the air chambers. For this we created a double-layered material in which pockets were formed between the two surfaces.

In knitting, it is possible to create separations in the textile by knitting independently on the two knitting beds. By using this technique we were able alternate between creating two separate layers and then "cross-over" so as to connect the layers back together again keeping the continuity of the surface. This strategy created tight pressings which in turn formed three dimensional pockets integral to the material production.

Defining Hyper Specification: Developing The Textile Pattern

In developing the textile pattern and material specification for *Listener* we created our own interfaces between architectural design software and CNC knitting. *Listener* is developed across a diagrid base pattern. The diagrid defines the holding pattern creating a base diagram from which the deformations of the pattern can be determined. Responding to an imagined scenario of occupation and interaction, our aim was to distort the diagrid creating fields of varying intensity, suggesting a higher degree of responsiveness around particular areas of the body.

The pattern is designed using parametric software that allows us to interactively programme the design environment. By creating attractor lines we control the geometry by pushing and pulling the diagrid pattern to form a non-repetitive structure with local deformations. The location of each intersection point in the diagrid and their relative distance is used to define the length of each of the three dimensional pockets. This resulting distorted diagrid is in turn used to develop a scripted interface to the CNC knitting machine. The knitting machine that we used is a Stoll machine that is run by an underlying machine code written in Basic. Bypassing the Stoll design software and writing directly in machine code allows us to create new interfaces between the parametric software and the Stoll machine.

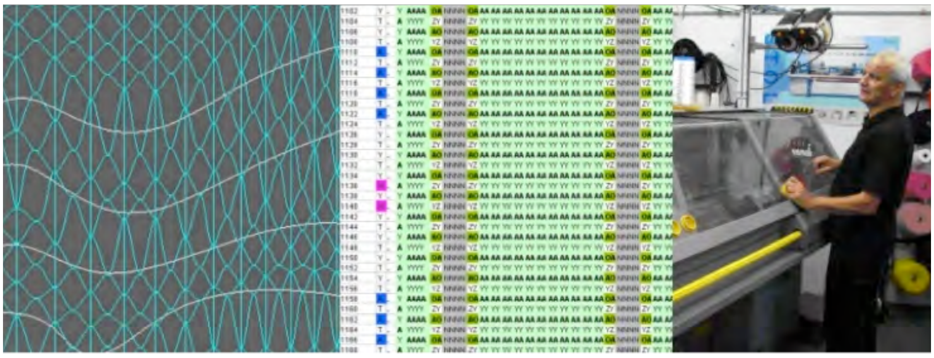

Figure 5. From diagram to code to knitting.

In the design we use the variegated point location developed in the diagrid to define a base structure for the material specification. Here, each individual knitting needle is addressed directly through the computer script. The yarn carriers are likewise defined thereby enabling us to embed the determination of the different fibre types and their location in the membrane as an integrated part of the script. In this way we were able to control the design of the surface stitch by stitch creating a graded material that is continually changing in its structural composition. The deformed diagrid acts as an intuitive and light interface for the Stoll machine. The interactive manipulation and adjustment of the attractor lines directly results in a re-generation of the computer code.

The parametric set-up proved essential for collaboration. During the development of the project we created an iterative design process characterised by the repeated amendments of the data definitions, the material structure and their interrelationships. For communication between the interdisciplinary partners we used Excel as a common platform for visualising the data structures. This allowed for intuitive reading and easy communication of changes to the design.

Considering Materials as Active

In *Listener*, the membrane is understood as active incorporating computationally steered events. In this way the project speculates on what happens as the materials we build our environments extend into the sensing and the actuating. If the maturing of technologies for digital fabrication has allowed the forming of a new practice focused on material performance, *Listener* also asks how this material perception can be extended into the field of active materials. As described by Cecil Balmond architecture is entering a practice in which the idea of a self-sensing and self-regulating building is possible:

> Today architecture is moving away from static compositions of inert building materials, towards dynamic interactive arrays of components and their interfaces, controlled by sensors, controlling devices and other feedback mechanisms integrated into the structures. These immersive environments can anticipate and adjust themselves to emergent pattern of their use and inhabitation" (Balmond, 2007). Referencing the current focus on ubiquitous computing and transitive materials the aim for *Listener* is to develop a smart composite with the transient qualities of computational material. (Coelho et al, 2007)

In *Listener*, the computational is directly embedded into the material design. Rather than integrating substructures for sensing and actuation as secondary systems, the material itself merges the structural and the active. The surface is composed of four different fibre types. Using Dyneema, a high-density polyethylene of extreme tensile strength, as the core substrate it withholds the impact of the air chambers and creates a neutral substrate. Two different conductive yarns were used to enable interaction. On the backside, a copper-based insulated wire was used as a soft antennae acting as a proximity sensor. As the users move their hands across the surface they effect a change in the magnetic field around the antennae. This change in capacitance is then used as an input to a microcomputer that in turn triggers a high pressure valve system making the integrated bladders inflate and deflate.

A second pattern of conductive fibres is knitted into the front of the material. These paths line the air chambers at either edge. As the chambers expand and contract they make the conductive paths touch. This continual shift in material connectivity is in turn used as soft switches (Berzowska & Bromley, 2007) effectuating secondary movement cycles that propagate through the material as self actuated waves. Finally, the three dimensional bulges themselves are knitted in a flexible lycra-based yarn. This allows the textile to expand and contract according to the triggered behaviour.

Figure 6. Composition of different fibre types in the diagrid.

The four fibre types are composed in relation to the underlying diagrid. In the material coding of the surface, each intersection point in the grid defines the layering and composition of the materials.

Programming Behaviour

The interactive behaviours in *Listener* are designed using a dedicated microcomputer. The coding of the reactive pattern between sensing and actuation is directly linear, each sense event triggering actuation. To be able to address the surface locally we devised a grid of individualised antennas allowing the surface to be locally addressed. Much like a touch screen, the different areas of sensing were assigned different inflating valves so that actuation occurs in proximity to the sensing. In a similar way each of the inflating bladders is locally addressed allowing us to drive the textiles as a distributed system. At present the surface is run as a centrally-steered computational system. The direct relationship between input and output makes the surface user-centric. In developing the system further, our aim is to implement a cellular logic where each cell acts as an independent subsystem interconnected through its ability to sense and act to its neighbouring cells. This logic will allow us to devise the surface as holding its performative measure creating emergent patterning in its reactive system.

Conclusion

The aim for *Listener* is to develop conceptual and technological models by which to think material specification in architecture. In response to the new digital platforms arriving through industrialised practices of mass-customisation and variegation, our aim is to understand how textiles can be used as a way of considering these practices at the scale of the material. Rather than thinking mass-customisation at the level of the element or component, *Listener* queries the possibility of directly interacting with material specification and production. Our objective is therefore not to suggest knitted fabrics as a material substitute but rather as an analogy for fabrication.

Listener reflects on a twofold integration of information-based design systems. Merging the computationally designed with the computationally steered the encoded logic of the surface is present both as a principle for material specification as well as a way to control its reactive behaviour. As such, *Listener* can be seen as an example of a new class of materials that are developed in direct response to the design criteria of their implementation. As performative materials, these combine locally-defined structuring as well as sensing and actuation.

As a speculative project, *Listener* asks to what extent such materials can be conceived and by which technologies we can imagine their production. In the development of *Listener* we have created our own bespoke interfaces for joining architecturally designed environments that parametrically controlled with CNC textile fabrication. This allows us to develop our own information-based materials created as an integrated part of the architectural design method. In the project *Listener* we have explored textiles as a model for conceiving and testing this new emergent practice.

Figure 7. Developing material as interface.

Perspectives

Listener further opens up new perspectives in considering knit as a material practice in an architectural context of making. As a process of fabrication, computer-controlled knitting can be seen as an additive process. As such it does not have the same issues of excess and waste that subtractive methods have. But, like subtractive methods, it uses off the shelf prefabricated materials in terms of fibres and yarns. These are produced within industrialised contexts and are therefore cheap to manufacture compared to other additive technologies. Most significantly, computer-controlled textile fabrication can use a vast array of materials. Where 3D printing technologies are highly limited in terms of materials, textile technologies can easily combine many different fibre types with differing performative and aesthetic qualities. Finally, textile fabrication creates structured composites. Manipulating the structural integration of fibres allows the designer to change the performance of the unified materials. In this way computer-controlled textile manufacturing provides a new way for the rapid prototyping of materials for architectural thinking and potentially for the rapid manufacture of materials to be directly used in architecture.

A second perspective introduced as part of the project development lies with the inherent dimensionality of materials. In developing *Listener* we have extended ways by which to define and develop non-planar materials. Where knit is fundamentally three dimensional and can be used to create materials that bulge and protrude, this is rare in building culture. Most prefabricated materials used in architectural design are planar and much effort is used to make them accept curvature. By providing a model for thinking material practice in architecture, *Listener* also discusses means by which complex forms can be integrated into material making.

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