

Prototyping shifts in design scale

The “Carotid thermo-regulator” as intelligent body architecture

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This paper explores the use of smart technologies like physical computing with a sensor and an actuator, to create a prototype of a wearable technology, which augments our interaction with the environment, and people. The initial design idea was based on an empirical study of varying body heat signature patterns corresponding to emotions. However, we are interested to expand the discussion beyond technical issues in the design process, to reflect on the broader relationship of the human body with space and people. The study raises some important questions vis-à-vis current mobility and scalar reduction of Technology today: What is the relationship between architecture and the human body? Can a wearable technology be used to indicate, and express a fluctuating emotion? How would a traditional garment element evolve to respond to a new requirement or program? What are the appropriate scales we should refer in order to design our surrounding space? What sort of expertise is required to shift in design scales?

Keywords: *Performance, Rapid prototyping, Physical computing, Micro-controllers, Human body, Scale*

This study is a sequel to the Reshape15 Competition, an international wearable technology design competition. The authors constitute the third prize winning team, featuring a design for a “Carotid Thermo-regulator”. The Competition considers fashion as a fertile ground for exploring physical computing and digital fabrication ideas addressing the following statements. “Data becomes beauty, interaction becomes emotion. As a result, a new aesthetic is emerging” (Reshape | R15 - Reshape, 2015). The project

benefits from funding from the National Council of Architectural Registration Boards (NCARB). The funding supported a new course aiming at integrating the practice and academic inquiry. The course is titled “Performative Parametric Design”, and employs the physical computing and parametric modeling as tools to address building performance.

The design team starts the investigation by looking at the fashion history across different cultures. During the research process, the team became fasci-

nated by different fashion trends; for example, ones that were developed to alter anatomy to fit local beliefs and aesthetic preferences. Some examples include the Egyptian head binding, Chinese foot binding, and Red Karen neck extension. The latter involves the use of brass tubing to form stacking rings pushing the jawbone up, and the collarbone down by coiling the tubing to add more rings. The team decided to focus on the design of a neckpiece.

The human cervical region has been celebrated by historical and contemporary fashion trends alike. Either through concealment or elaborate exposure, tailored garments and accessories like the “Ruff” have been used since the 16th century to prevent the shirt from being soiled. While some versions of the former denoted an aristocratic provenance, the latter has been associated with radicals, academics, philosophers, intellectuals and politicians. The design of ruff has changed over time, and become a shirt collar. The team would like to transform the more familiar neckpiece by giving it a new function to investigate how a traditional typology can be transformed. A previous study on temperature map as a result of emotion piques our interest (Nummenmaa, 2013). However, it requires an extensive network of sensors in order to detect the pattern. A temperature change may indicate a mood shift.

This project re-imagines this area of the body through a prosthesis, which extends aesthetic preoccupation to consider the regulation of thermal comfort (Fanger, 1970). Our premise stems from the traditional Ruff which evolved from a small neck piece to high ruff or collars during the Elizabethan era. Historically, ruffs have shrunk or enlarged transforming into cuff and skirt through evolutions, incorporating wooden support in some iterations (Hughes, 2011).

PROTOTYPE DESIGN & PERFORMANCE

Our proposed carotid prosthesis embraces physical computing and anatomical expression to create a dialogue between technology and nature. The design considers a garment as a vessel for the human thermal adaptation. Interestingly, body tempera-

ture amplitude and patterns correlate to standard biophysical incidences like the heart and respiratory rate as well as emotion (Nummenmaa, 2013; Davies, 2009). The garment includes a microprocessor, sensor, pump, wearable enclosure, closure, fasteners, and heat exchangers (Figure 1). A pulse sensor is placed over a carotid artery area to detect a temperature change in a non-invasive manner (Childs, 1999; Buller, 2013; Imani, 2016; Jay, 2013). Its reading from the Carotid artery controls a peristaltic pump transferring the body heat to the heat exchangers/sinks similar to a fluid cooling system for an electronic component such as a computer CPU. The pump circulates a fluid medium in a closed loop tubing system passing through inline heat exchangers that dissipate the collected heat through the natural convection.

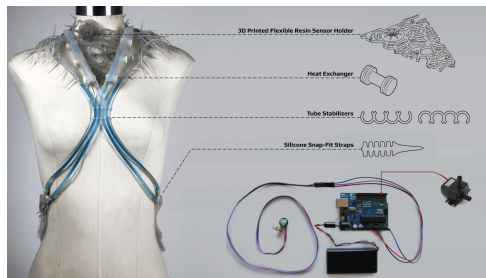


Figure 1
A diagram showing component assembly of the design. A pulse sensor connected to an Arduino controls liquid flow through a pump.

Integrating these components within a wearable item, the team carefully considers minimum weight and non-disruptive user presence. Soft sheet materials like silicone rubber and flexible resin are employed. The silicone sheet can be laser-cut to form the back closures, fasteners/ties and the enclosure; while other custom elements are 3d-printed using the flexible resin to achieve geometrical complexity. The silicone sheet serves as a primary (inner) layer for attaching a ‘soft’ 3d-printed layer, which in turn secures the liquid-tubes (Figure 2). To ensure skin breathability, a pattern of holes is cut from the silicone surface using a parametric definition, which translates color data from thermal IR imaging of users’ cervical area into a gradient pattern (Figure 3).

Figure 2
An Infrared thermography of the wearer's cervical region (One of the authors is used as reference for pattern generation).

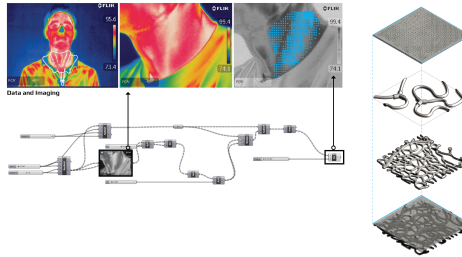


Figure 3
A laser-cut silicone sheet for the flexible piece framing the neck.

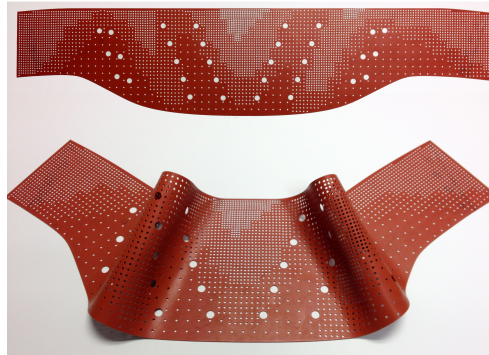


Figure 4
Design Process: Early sketching using proportions of the human body; early prototype with silicone rubber; final prototype.

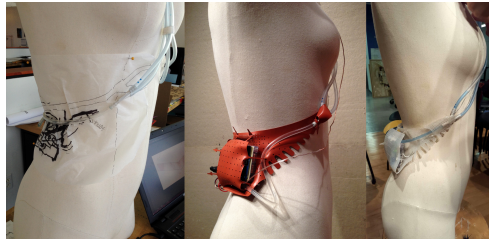
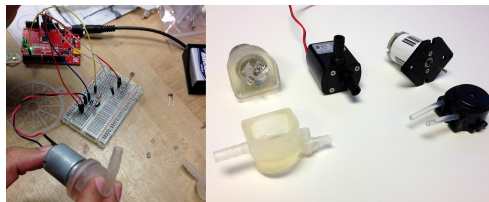


Figure 5
Testing of 3D-printed pump; Design Iterations for liquid flow control: 3D-printed pump (1), off the shelf pump (2) and peristaltic pump (3) used in the final prototype.



The effect resulting from the transformation of thermal data into graphic becomes an inherent ornamental quality of the piece. It provides a clear reference to the internal blood vessel network of the neck; this component secures the heart rate sensor and tubing and is attached on the silicone piece via a number of fasteners, feather-like barb ties that act like buttons or toggles. The designs of the barb ties and the back closures are inspired by barb ties used to hold thermos-formed plexiglass pieces in an installation led by Phillip Beesley as a part of the class activity (Phillip Beesley Architects, Inc., 2015). The back closures mark the top of the spinal column, cervical vertebrae. Its repetitive arrangement is similar to the cervical vertebrae to further reinforce the idea of reflecting the anatomy onto the garment. In addition, ties are also used as ornamental elements to create a silhouette similar to a fur collar used to provide warmth in winter.

The original plan includes the integration of the pump into the 3d-printed layer in order to remove attention from that area to the higher part of the neck where the sensor is located. However, the size of the pump that we have is too large. For the prototype, the pump is located in a pouch made of a laser-cut silicone sheet, and located in the lower back region (Figure 4). The shape and arrangement of tubes follows the diagram of blood vessels and hot spots in infrared reading in order to effectively transfer body heat. The prosthesis serves as a fashion statement, celebrating the importance of the cervical area as a liaison between the central body organ (heart) and the body's processing unit (brain).

A centrifugal pump is the vehicle for moving the liquid medium through the network of tubes (Figures 6, 7). This device was designed to move the cooling heat exchange liquid by transferring rotational energy from one or more driven rotors. Fluid enters the rapidly rotating chamber along its axis through an inlet and is propelled by centrifugal forces through the outlet. The use of a stereolithographic (SLA) resin 3d printer was advantageous for achieving specific design outcomes: to be symmetrical and centrifugal in

the interior chamber in order to direct water flow accurately, ergonomic on the exterior to create a homogenous connection with the pouch, and finally for it to be water-tight. The two-part pump (Figure 5) was created using SLA Form Labs printer and then assembled together manually. The lower part of the pump included the centrifugal container which holds the liquid in a chamber and also has an inlet and outlet. The upper part, or cap, houses the rotors which were cut and formed from thin ply sheet metal. This version included two rotors that direct the flow towards the outlet. One major design challenge with using a traditional pump was creating a water-tight system. Problems were posed during prototyping in which the laser-curing of the 3d-printed parts created moments of porosity and the upper and lower parts were not sealed together properly. As a result, prototyping the pump was abandoned in view of a tight time-frame when the project was taking place (2015) and instead, a readily peristaltic pump was integrated in the assembly (Figure 6).

BUILDING AND BODY : CRITERIA ACROSS SCALES

The correlation between Clothing and Architecture has been noted by several architects in the past, including Adolf Loos (*Gesetz der Bekleidung: Law of Dressing*), and is presently revived through research that utilizes the latest technology in digital fabrication, integrating “smart” layers within daily garments. The consideration of “smart clothing” which is connected online and allows the adjustment of parameters through portable technologies like smart phones is promising because it can be situated within a broader framework of energy conservation: perhaps it is more efficient to control the micro-climate around our body, instead of the temperature of an entire building. The design of responsive wearables should not be seen necessarily independently from the architecture around them, even if these could indeed function autonomously. There is some merit in contemplating the performance of a system across scales. As architecture becomes increasingly interac-

tive, it may reconcile the performance of the building with that of its users through smart prostheses within clothing (built-in sensors, kinetic components) that control building accessories (eg. parts of a building's façade) or, reciprocally, are controlled by the building's behavior in reference to a particular criterion. For example, if the external temperature on a building shell - recorded by built-in sensors on the façade - exceeds a certain level, a switch for operating the pump on the interactive collar could be activated, thereby reducing temperature locally (neck area) to offer relief from the heat. This may be a significant step towards reducing energy consumption for cooling buildings in warm climates, as the micro-climate induced by the clothing could compensate for a portion of the temperature shift necessary to reach the desired range of thermal comfort: in order to maintain a benchmark temperature for optimum comfort within an office building - i.e. 23-26 degrees Celsius (73.4F- 78.8F) in the summer- one may use A/C to get closer to the desired temperature, then regulate the temperature around the body to reach the final value, achieving substantial energy economy.

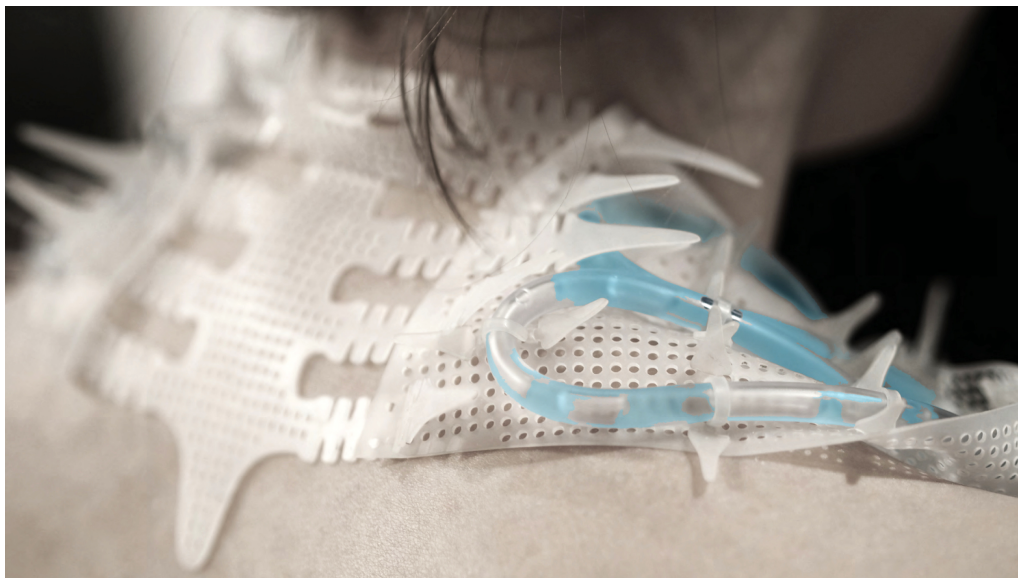
In this sense, we may consider the building and the human body as two separate parts of the same (digital) circuit which are connected with each other. According to the late Bill Mitchell, Professor of MIT's Media Lab, this circuit - which is in fact, the internet- acts as a receiver of signals from the human body, which are then translated through clothing: “Clothes have traditionally shaped our first interface with the physical world as much as our personal electronic devices or intelligent clothes are now creating interfaces between our nervous system and the worldwide digital net.” (Mitchell, 1996). Objects at a wearable scale, may therefore belong to a larger wireless network which includes building systems at large.

In the context of “design thinking” architects have a lot to learn from this reciprocal scalar transition; an exhibition on design and science (*Design and the Elastic Mind*, MoMA 2008) addressed this overlapping of scales. According to the exhibition (and MoMA's Architecture and design) curator Paola

Figure 6
Final prototype for Carotid Thermo-regulator, using custom-made 3D-printed and laser-cut components: overall assembly; photocell used to test the wearable liquid circuit, replacing the heart sensor as a trigger currently (The pulse register will be integrated in a revised version); Pump; power source; Arduino micro- controller.



Figure 7
Liquid medium flowing through tube network to transfer heat from the neck region to heat exchanger.



Antonelli “...what we discovered was that scale was no longer a matter of size, but rather a matter of complexity...It doesn’t make sense any more to distinguish design disciplines because of the materials they use, the dimensional scale they tackle, or other old-school kinds of criteria.” (Antonelli 2017) While this cross-scalar connection exists, it is critical for architects to understand how to extrapolate principles from one scale to another; in his essay “Size Matters”, Neil Leach reminds us of the 1977 film “Powers of Ten” by Charles and Ray Eames (Leach 2017), which illustrates aspects of life ranging from the entire universe to a single quark. Today’s digital tools for drafting, he observes, have no scale except at the moment of printing (or prototyping). We should, therefore, be cautious to not dismiss the differentiation of material performance at different scales, as scaling an element in 3 dimensions exponentially changes the volume, which means that material behavior changes radically. Leach gives an example of both organic matter (bone) and man-processed material (steel); proportionally scaling the material skeleton of a high-rise building (i.e. Empire State) would not suffice, we would need to reconfigure its structural logic as scale increases (see Flotsam & Jetsam, SHoP Architects, 2016).

COLLABORATION STRUCTURES AMONG DESIGNERS: CRITERIA ACROSS DISCIPLINES

The aesthetics which are formulated through the incorporation of technological accessories in wearable solutions is for the moment loosely defined, due to its infancy. Nevertheless, an ongoing discussion is already taking place among architects and other artists and fashion designers. Early discussions on this topic were instituted during a symposium organized by architect, professor and theorist Neil Leach, and titled “Body Architectures” (2016). Fashion designers like Iris Van Herpen and Mary Katrantzou are introducing rapid prototyping technologies and smart accessories to produce unique garments which consider performance beyond clothing’s rudimentary func-

tion or artistic appeal, to address some Performative aspect of their design. In doing so, they often reach out to architects like Behnaz Farahi, Nicolo Casas, Neri Oxman and Philip Beesley.

Beyond our daily practice of technology and its performance, it is important to situate this design work within a discussion on Architectural theory and responsiveness in architectural education. The work presented in the aforementioned symposium (“Body Architectures”) delineate our intention as architect for an explicit shift of Scale in our work especially in dialogue with other fields like fashion design and art. Can the future projection of this tendency forecast an impending augmentation of the required skills in architecture graduates? Will this challenge the traditional architectural pedagogy towards greater collaboration with external consultants like engineers and programmers within the curriculum? It is worth considering the notion of “design agency” as such design protocols become more popular, because the concept of intellectual property assumes a broader, more collective character.

In this collaboration among designers of various crafts, the visual dimension of Architectural output should not be overlooked. According to Paola Antonelli, the formal expression can serve as a tool of communication: “I have always insisted on the fact that physical elegance...is a form of communication...in nature the first means of communication is form...if you were able to take a complex scientific concept and manifest it so that its gorgeous appearance cuts across resistance and disbelief, then you’re going to have a better chance...to reach a wider audience” (Antonelli 2017). Notwithstanding the performative requirements of the Carotid Thermoregulator prototype, its aesthetic expression is fundamental as this is situated within the context of fashion, and - referring back to Antonelli- may depend on the visual capacity of form to communicate the complexity of the systems involved through an embedded visual (formal) elegance. It is interesting to note that the design of the prototype transformed considerably as the design process revealed constraints related to the

physical computing aspects and also the circulation of the fluid.

CONCLUSION

The human body can be identified as the inherent network of interior and exterior organs protected by our outer layer, the skin. Throughout the years we have created tools or garments that enhance our interaction with the environment (eg. shoes to protect from uncomfortable surfaces, sweaters to mimic the use of fur, and more recently, the smart phone to amplify our computing power and memory which is arguably attached to us as often as these garments). Does this make us unofficially cyborgian by default? As discussed earlier, the notion of the “extended body” has preoccupied several designers and theorists in the past, and current scaled digital technologies have facilitated the integration of smart devices within a wearable context. We are interested to discuss the potential of approaching a design problem from a perspective of product design, interactive performance and aesthetics, assessing their reciprocal dynamics in the process, as well as a resulting visual language which echoes the current constraints of material and portable technologies.

If the human body is a network of systems working together internally, and our tools and garments are only individual enhancements, how can we shift the focus to allow for a unified network of systems which are integrative to create a smarter, yet more playful, humanitarian experience? There is, naturally, a margin for optimizing this as a “product”. It should be mentioned that the “Carotid Thermoregulator” was designed and prototyped before the dissemination of work of similar context, like the projects featured in the “AD: 3D-Printed Body Architecture” issue (2017) - even if some of that work was in progress at the same time (2015). Unlike these projects, this work is not entirely dependent on 3D printing; in fact, it is possible to fabricate without a 3D printer. Considering the advancements in 3D printing, there are potential benefits from integrating this technology to evolve the next generation of the prototype into

a more compact product which can be seamlessly integrated into our range of existing fashion accessories. In order to better address the objective of the wearable, which is to circulate liquid effectively and provide visual integration as well as thermal insulation, perhaps research on material customization/-combination within one prototype should be examined (see the work of both Neri Oxman and Behnaz Farahi). During this investigation, one should keep in mind the idiosyncrasies involved in material performance when transitioning scales (Leach 2017).

On a broader level of architectural discourse, this work promotes design thinking and criticism with regards to the role of the architect and our “Agency” in the act of design; during the mid-2000s, the emergence of digital fabrication promised, according to some practicing architects and researchers (i.e. Kieran Timberlake) the repositioning of architects in the center of the construction process, giving us more control. This broadening and strengthening of the architect’s position sort of echoed the lost Brunelleschian model of the “master-builder”, which had disappeared effectively since the split between design and construction was initiated by Alberti in the Renaissance. Interestingly, Neil Leach suggests that the same Digital Fabrication technologies are today promising for almost the contrary - they allow graduates with architectural training to be absorbed by similar but other industries like fashion design, food, jewelry, etc. and find a home thanks to the skill-set inherent in our training. This points to a return to the spirit of the Bauhaus, which according to MOMA’s Paola Antonelli, is necessary vis-a-vis the blurring of scales across design fields: “Everybody who studied at the Bauhaus went through a primary curriculum that was very much about learning the rudiments of all the arts, and then branching out. That kind of initial core is, in my opinion, still extremely important...if you have a strong engineering, historical and theoretical background then you can move in any direction you want.” In a technologically-driven society where specialization is on the rise, it is interesting to consider revisiting architectural education towards a

more generalist approach which can render Architecture graduates even more robust, ready to face a design industry where scales, tools and skills overlap.

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