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VARIABLE POROUS MORPHOLOGIES
Programming Wall Bending Behavior To Induce Specified Curvatures

In the light of the advances in the field of interactive architecture, one can see an increased ease of access to programming it, not only targeted at architects but also at users of such enhanced environments. This potential was explored throughout our project by creating activity-driven and user-preference reconfigurable spaces. Thus from a theoretical point of view there were three main points in which the GSM 3 symposium content resonated with the principles in which the project is founded. Firstly, the concept of mutual programming, as explained in the lecture by Keith Green, comes in play. A space that is malleable and dynamic to a certain extent implies that it will be modelled by human behavior, as well as vice-versa, new habit patterns will emerge as a result of people's communication with these mechanisms.

The other two points on the other hand were mentioned in the interview of Michael Hensel. One stated that we need a degree of recognisability in order to make the shift from standard to non-standard, thus avoiding an appearance of the latter as foreign in the eyes of the observer. This reasoning stood behind the decision to make the floors and circulation somehow familiar and make only the vertical walls flexible to potentially prevent a lack of orientation. The other statement by Hensel was about finding an adequate material system by considering the available resources as a palette. Apart from being used in the large scale to provide users with a palette of predefined configurations to choose from, this concept is taken into consideration constantly while producing prototypes of the wall material. It is important to explore the possibilities of taking the theoretical implications into practice, since that consists of the basis of design to robotic production and operation.

As a result of space reconfiguration, a halved portion of the wall making up one unit resulted in five alternate positions [Fig.1], which differ also in terms of curvature, sometimes conflicting between the several cases. In order to achieve the required level of flexibility, the aspects to be addressed are materiality, actuation and optimisation. The first prototype was created using silicone rubber, a highly stretchable material applied in soft robotics mainly due to its elastic behavior and moldability (Kim et al. 2013). Local extension differentiation

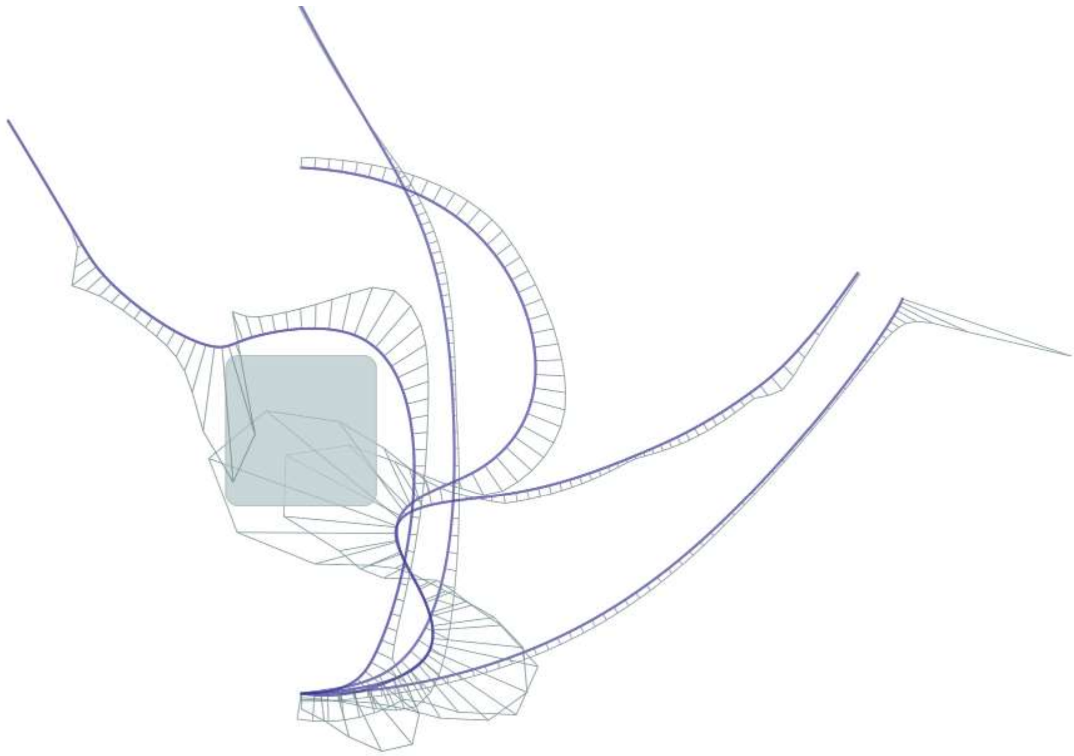

Fig.1 Five different configurations of half the portion of the unit wall and their respective curvature mapping

between inside and outside of the wall was thought to cause the alternation between the desired curvatures, thus silicone rubber was able to fulfill performance requirements since it can be extended up to six times its initial dimension and has a curing time of only four hours ("Dragon Skin Series Technical Bulletin", 2016). Taking inspiration from the bendable properties of tree branches, that are facilitated by their inherent capillary morphologies (Van Casteren et al. 2012), porosity was employed in order to achieve the desired property grading. More porosity was associated with more extension whereas low porosity stopped the material from extending, as seen in the first specimens [Fig. 2]. Metallic frames were to be put inside in an indented fashion in order to produce a dividing barrier between the two layers of the wall, as well as providing enough structural self-bearing support and vertical stability.

As far as actuation is concerned, the metallic frames were thought as electromagnets (Laplante, 2005), wrapped with a solenoid-like copper coil that would alternate in terms of wrapping direction in order to charge the metal with similar poles near each other, that would result in each frame pair pushing away from each-other and the material extending. A constant porosity throughout the material would result in a uniform extension, with the same angle between the frames, while a gradient-induced porosity changing along the longitudinal direction of the wall would cause a gradual extension from a rigid part of the wall to the most extendable one [Fig. 3]. Applying the same principle but in the perpendicular direction, thus mapping porosity as a gradient from outside to inside would give way to creating curved geometries. Such reasoning was applied to optimise silicone porosity in the first prototype, conceived to achieve a sinusoidal shape to observe the curving behavior first without integrating the actuation mechanism yet [Fig.4]. It was discretised to the three available sizes of perforating cylindrical elements resulting in three degrees of porosity [Fig.5]. The resulting prototype exhibits an emerging sinusoidal geometry under exerted compressive forces [Fig.6] that simulate the magnetic actuation, as well as under bending forces [Fig.7]. This confirmed the hypothesis posed before the experiment, showing how porosity affects the behavior of the material in terms of curvature. In addition, bending the prototype to guide it into a concave shape in the zones designed to be convex and vice-versa proved to be blocked to a certain extent by the embedded morphology of the material.

Fig.2 Stretching capacity of each sample, the one with more porosity on the left and the less porous seen on the right

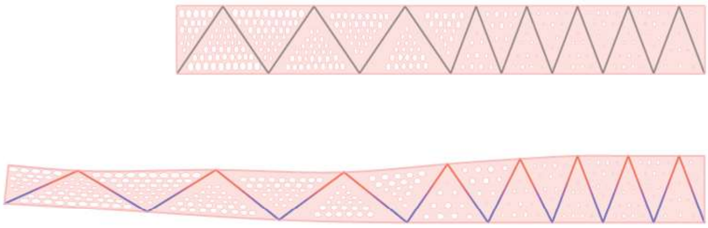

Fig.3 Longitudinally differentiated elasticity of the wall. Silicone shown in pink and metal frames in grey, while red and blue show the charged state of the electromagnets

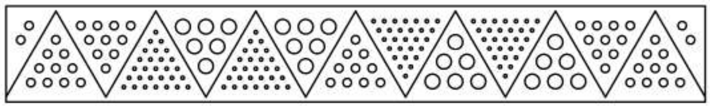

Fig.4 Optimisation of porosity in a sinusoidal manner and discretisation into three pore sizes

Fig.5 The three different perforating cylindrical elements and the resulting porous prototype

Fig.6 Specimen under compressive forces

Fig.7 Specimen under bending forces

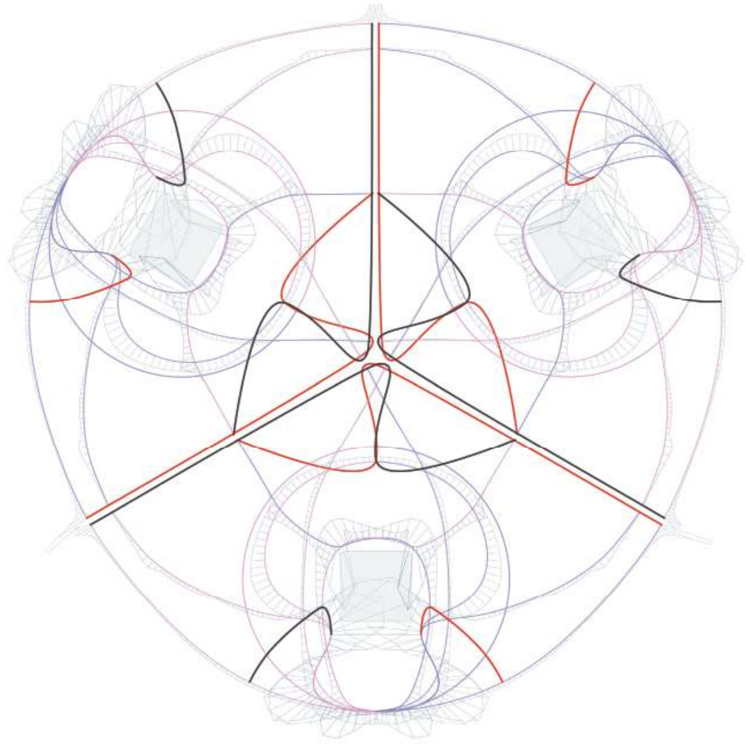

Fig.8 System of rails for a cluster aiming at the least number possible of rails, placed at the main control points according to the curvature

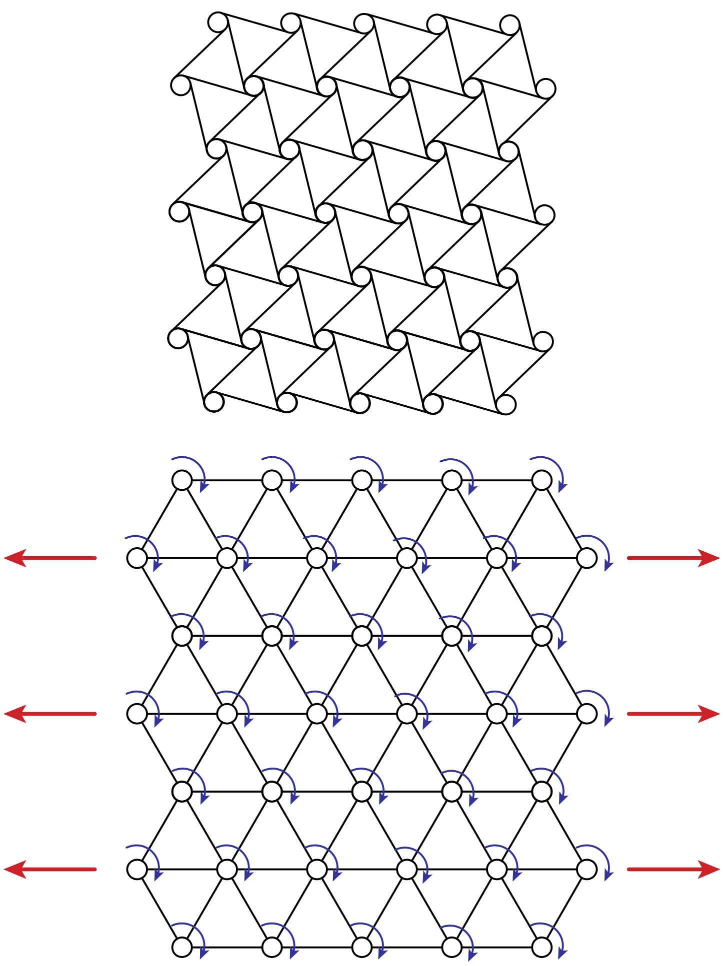

Fig.9 Auxetic system: transversal extension in case of longitudinal pulling, circular pattern applied

Fig.10 Auxetic system: elevation sample showing the lofted geometry in line with 3D-printing layers and circle variation

However, there were several drawbacks in the produced sample that pave the way towards further development of an appropriate material system, in addition to several implications inferred from the GSM. The heaviness of silicone rubber and level of optimisation both imply that more refinement of the porosity is needed, as well as a translation of perforation also in other directions other than the vertical one. Such changes could be challenging given the properties of the material, that make it lose rigidity when highly porous, thus a more stable semi-flexible material could be considered, such as a 3D-printing filament containing thermoplastic polyurethane. In this aspect, the GSM lecture by Justin Dirrenberger gave insight into architectured materials and his technical approach coming from a material science perspective provides several directions in which the prototype could evolve. In his research what seemed to address porous morphologies the most was the theme of auxetics, where the differentiation of the microlattice's pattern influences Poisson's ratio and thus models elastic behavior (Dirrenberger, 2012). Most materials shrink transversally when extended longitudinally but the opposite happens to auxetic ones that have a negative Poisson's ratio and extend transversally.

Alternating the pattern between auxetic or non from the inside to the outside of the wall consists of an apparatus that stops the wall from getting into undesired curvatures while moving to achieve one of the five configurations (Park, 2015). The actuation was thought to be simplified and made into a system of rails [Fig.8], taking a hint from the remarks of Michael Hensel, who stated that even in nature you do not have a complete full optimization because it comes at an excessive evolutionary cost. In addition, the energy required to make the magnetic actuation system function was high as well. Thus the next steps would include variating the pattern, thickness and size of the lattice. For example, in a circular based pattern [Fig.9] the circle section should be the oscillating variable because it controls the transversal extension. Finally, since the lattice will be 3D-printed, delamination should also be kept in consideration, thus the lattice would resemble a lofted geometry rather than a network because of the instability of the layers printed in extreme angles [Fig.10].

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