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Knitectonics

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Abstract

"...techniques that operate on a material level, if we need ideas, will follow from techniques and techniques follow from matter..." - Gottfried Semper (1989).

Can a simple household craft facilitate a proto-tectonic system?

The project Knitectonics aims at exploring digital fabrication systems that facilitate optimized, adaptive and specific integrated architectural solutions (Malé-Alemany, 2009). It is inspired by the beauty of nature systems with their inherent efficiency and performance. The research explored on-site fabrication of monocoques[1] shells, integrating skin and structure along with services and infrastructure, using a simple household technique. It thus embodies a self organized micro system of textures and a macro system of structures. This paper elaborates how the numeric aspects of a textile technique were used, first to digitally imitate the process of assembly and further exploited to develop and visualize a novel fabrication system, based on material research and technical experimentation.

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[1] The term 'Monocoque' comes from the greek root *'mono'* meaning single and the French word *'coque'* meaning shell and is a construction technique that utilises the external skin to support the structural load.

Keywords: Digital fabrication; emergent architecture; evolutionary architecture; textile architecture; knitting; design research.

1. Introduction

A natural harmony has always existed between machines and mathematics, and this synchronization directed scientists to modern day computation. The Jacquard loom, with its wooden punched cards, was the first mechanical device driven by a binary pattern. It brought forth the idea of programming and further inspired Charles Babbage to develop the analytical engine (Chisom, 2011). Ever since the industrial revolution, techniques for manipulation of fibers into textiles have not been domestic craft- based procedures and neither have the materials been mute. Together they have been revolutionary, so much so that today they are used for various high performance purposes like aircraft building. All these techniques are about material placement, to differentiate surface pattern and form geometries. They are in close congruence to architecture but in absence of a design and visualization tool, their potential has not been fully harnessed.

The deep rooted relevance of textiles in architecture is apparent in the theoretical works of the 19th century German architect Gottfried Semper, who deduced textiles to be the first technical art (Semper, 1989). Lars Spuybroek further envisioned soft elements becoming rigid through collaboration using various textile techniques. These theoretical intuitions along with the capacity of available ‘techno textiles’ could be united with simple machinic processes used in the textile industry. To that end, numerous techniques of Interweaving (like fiber placement, 3D weaving and stitching), Intertwining (like braiding and knotting) and Interloping (knitting) were studied and experimented with.

The primary objective of the project was to achieve complex geometries with inherent ‘economy of means’, such that material is placed optimally where it is required. Monocoques, where skin is the structure, visibly illustrate this and the aim was to extend this economy to other parameters of material, machine, infrastructure, energy, time by creating ‘self structuring forms’. The technique of knitting uses the potential of the continuous mono-materials of the fibre realm and presents the possibility to materialize unified structures without formwork, as against other textile techniques which require extensive machine setup and formwork. Hence, re-interpretation of an existing method and articulation of sophisticated programmability of the machinic system to explore novel architectural design processes will be demonstrated here with the technique of knitting.

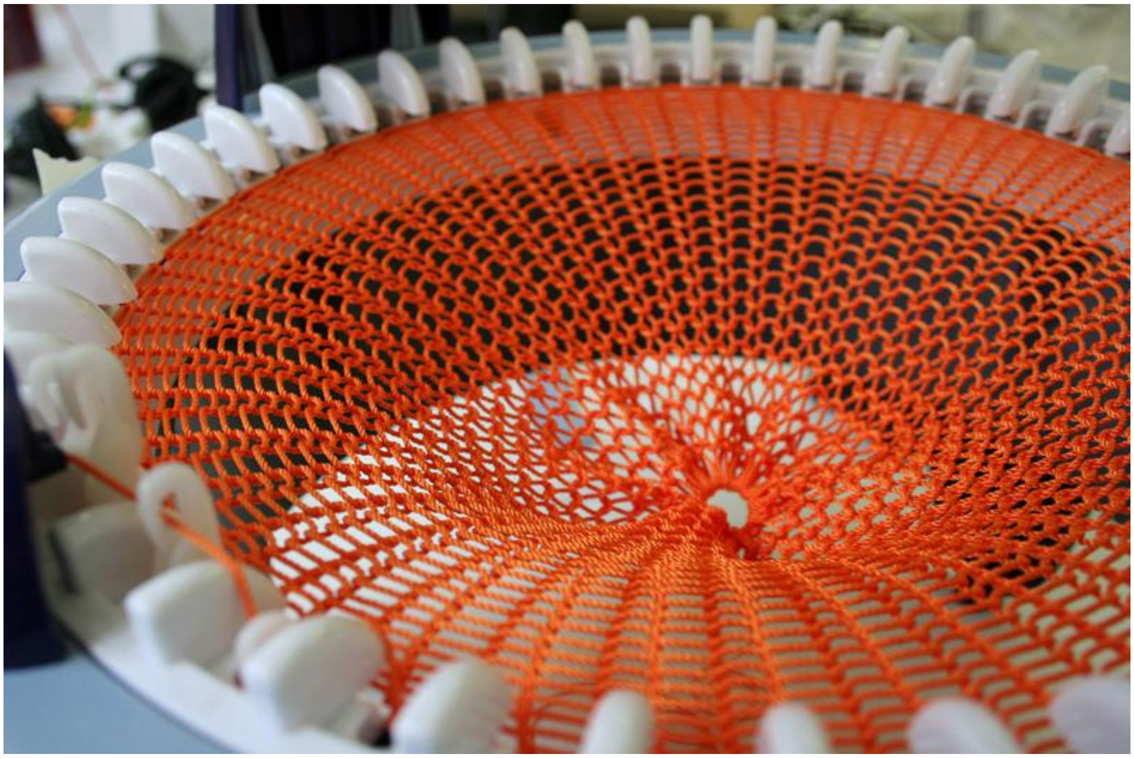

Figure 1. Household Circular Knitting Machine.

2. Evolution of the Machine

The process followed through the project was a parallel dialogue between analogue experiments, done on a household circular knitting machine (Figure 1) and digital simulation, done in Java language on the 'Processing' platform. After understanding the machine, method and metaphor of knitting, the challenge was to explore the tectonic possibilities presented by the technique, resolve the issue of scale as an architectural prototype and adapt the system for on-site deployment. The first step to a solution was to connect two or more machines with a bridge, inspired by Benito Manini's 'knitting machine for producing tights'[2]. So though the conceptual prototype design of the machine started with a household circular machine, it evolved through rectilinear, cross and hexagonal configurations, to eventually come back to a circular configuration, connected with bridges in a hexagonal grid (Figure 2).

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[2] Benito Manini, 1993. Knitting machine for producing tights. *United States Patent*, number 5,226,297. 13 July.

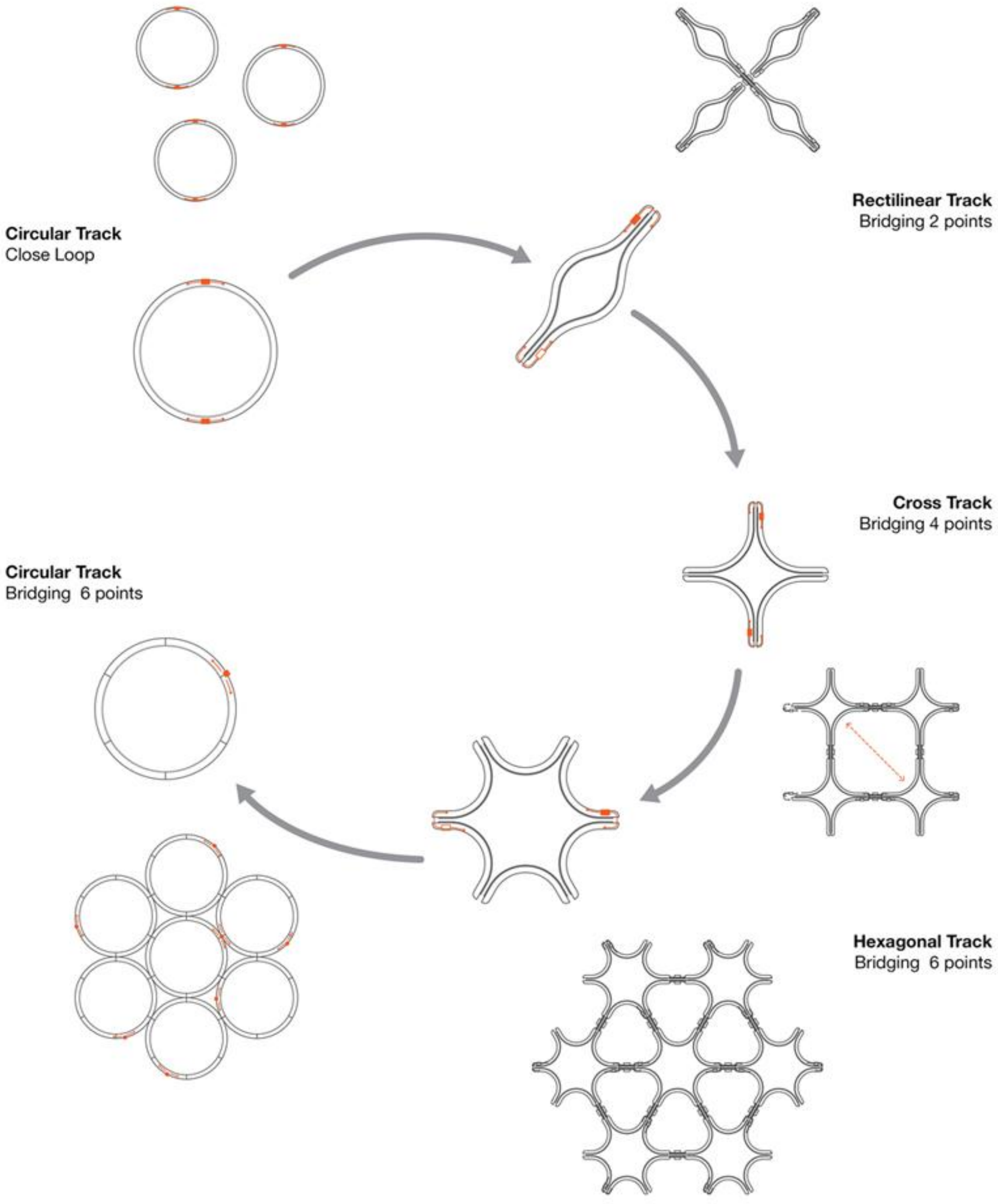


Figure 2. Evolution of the Machine.

To be realistic as a fabrication process, the digital setup of these circular knitting machines with bridges would require additional processes. To deploy structures without formwork with this system, the proposed ‘knitting ring’ would move up as it knits and the knitted fabric would be tensed using a replica of the machine configuration ‘attachment ring’ on the ground. Another critical aspect was to achieve structural rigidity, the suggested solution for which was to use fibers impregnated with resin, solidified to shape with UV light from the 'solidification ring' (Figure 3). To investigate and simulate systemic aspects and topological complexity with the knitting-solidification machine, it became imperative to construct a digital machine. The idea was to create a simulation system that could digitally imitate all parts of the machine and their actions, which together would create a knitted structure. Thus the tools together represent a new language of assembly and will be explained here as three phases.

Figure 3. Knitting – Attachment – Solidification Rings.

The first phase of developing a 'decoding tool' involved understanding and decoding the knitting action of the machine and the material properties of the fibers used, and then translating them into fabric and its behavior. The tool facilitated in appreciating and speculating patterning, topologies and behavior, beyond the capacity of the analogue machine.

In the second phase simulation helped conceptualize the 'design apparatus', with the interface as a fabrication blueprint. Design apparatus is based on the systemic comprehension of a simple machine, wherein the constructed fiber articulates surface and layering seamlessly and the trajectory of a single line gives one, two and three dimensional geometry (Baurmann, 2010). The interface allows selection of size and configuration of machines, type and properties of fibers, dynamics and equilibrium of the system and the course of action of the fiber feeding 'agent'. The algorithmic routines facilitated the option of pre-programming or real-time sequencing of heads and visualizing the outcome. The digital machinic system was then applied in a selected scenario, to test and demonstrate the tectonic capacity of the method developed.

The third phase proposed a 'generative tool' which could be developed to precision in the future, to evaluate, select and optimize. The digital systems offers various ways to set up, sequence and control the machine, such that the system does not provide a single accurate result, but multiple appropriate solutions. The constants of the system, i.e. the ‘chromosomes’ are varied to achieve a random population. These iterations are evaluated against the prescribed parameters and then bred over ten generations to obtain appropriate architectural solutions.

3. Decoding Tool

In the initial phase of digital simulation, the decoding system could simulate different yarn with varying properties, openings, different patterns and solidification, under the effect of gravity and time (Figure 4). The simulation was primarily focused on digitally imitating fabric behavior and patterning, with the understanding of the analogue machine.

The parts of the machine executing different functions were split into tasks in the simulation system, such as the tracks, the yarn feeder and the bridge connections. The simulation was scripted in ‘Processing’ (Frey and Reas, 2010) and for simulating physics an additional library ‘Toxiclibs’ (Schmidt, 2010) was used.

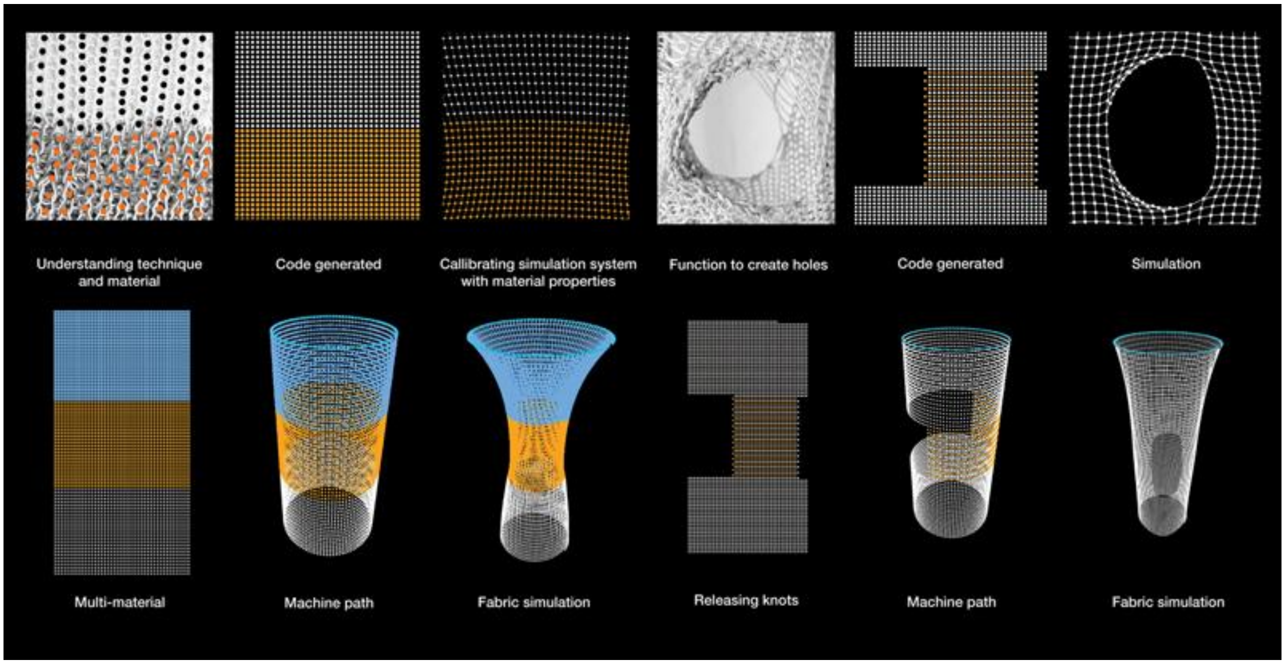


Figure 4. Analogue and Digital Decoding Process.

3. 1. Parts of the System

- Needle: is the smallest performing component of the mechanic system. It inter- loops the yarn to create the knitted fabric, while holding the knot for inter looping the next set of knots.
- Bed of Needles: is a segment of the track, which is a support base for the needles. Each bed has a certain number of needles and a "bridge" at the beginning of it.
- The Bridge: is a point where two beds of a track are linked. These also become the connection points for bridging with other tracks.
- The Track: is composed of six needle beds and it carries the information required to create a specific size machine, i.e. the radius, total number of needles etc. These parameters then determine the specifics of the bed and the needles. Each track has six beds and thus six bridges, every 60 degrees, which connect to other tracks (Figure 5).

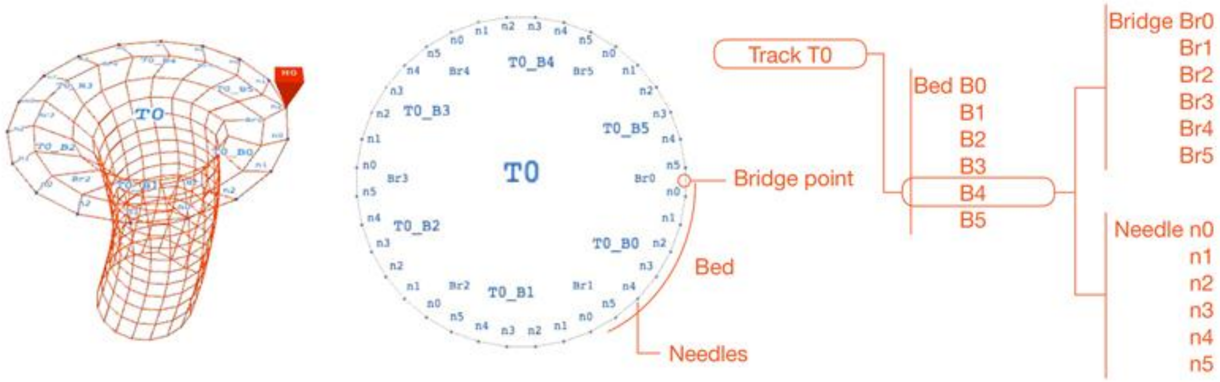


Figure 5. Machine Anatomy.

3.2. Knitting Action

The knitting process on a physical knitting machine involves each needle to create a loop. This loop is retained until the yarn interloops to create a new loop, following which it is dropped to create the fabric. So each knot is singularly active on the needle and once it is off the needle as a part of the fabric, it is under collective action. In the simulation, each knot on the needle is represented by a 'particle'. These 'particles' are then dropped just like the knots and the resultant fabric can be described as a 'number of particles' connected with 'springs', which are the digital equivalent of the yarn.

3.3. Knitted Fabric

Each yarn used in knitting has specific properties and it was imperative to embed this data into the simulation to get a real picture of the material behavior. As the knitted fabric falls with gravity, the behavior of the yarns governs the behavior of the fabric. So in the simulation script each yarn was imparted the following characteristics.

- Physics: The knots of the fabric are represented by ‘particles’ connected with ‘springs’ from the physics library. These ‘particles’ are subjected to forces of gravity and other springs around them, as the knots are relational and impact each other.
- Yarn Strength: The yarns are differentiated by the strength of the ‘spring’ of each yarn. Spring strength is defined in a range of maximum stretch and maximum compress and has an ideal rest position, such that the springs under all forces are always attempting to come to that rest position.
- Yarn Weight: As the force applied on an object in the product of its mass and the gravitational acceleration to calculate the force on the yarn, gravity is declared as a global variable and weight of each yarn is established in yarn properties (Figure 6).

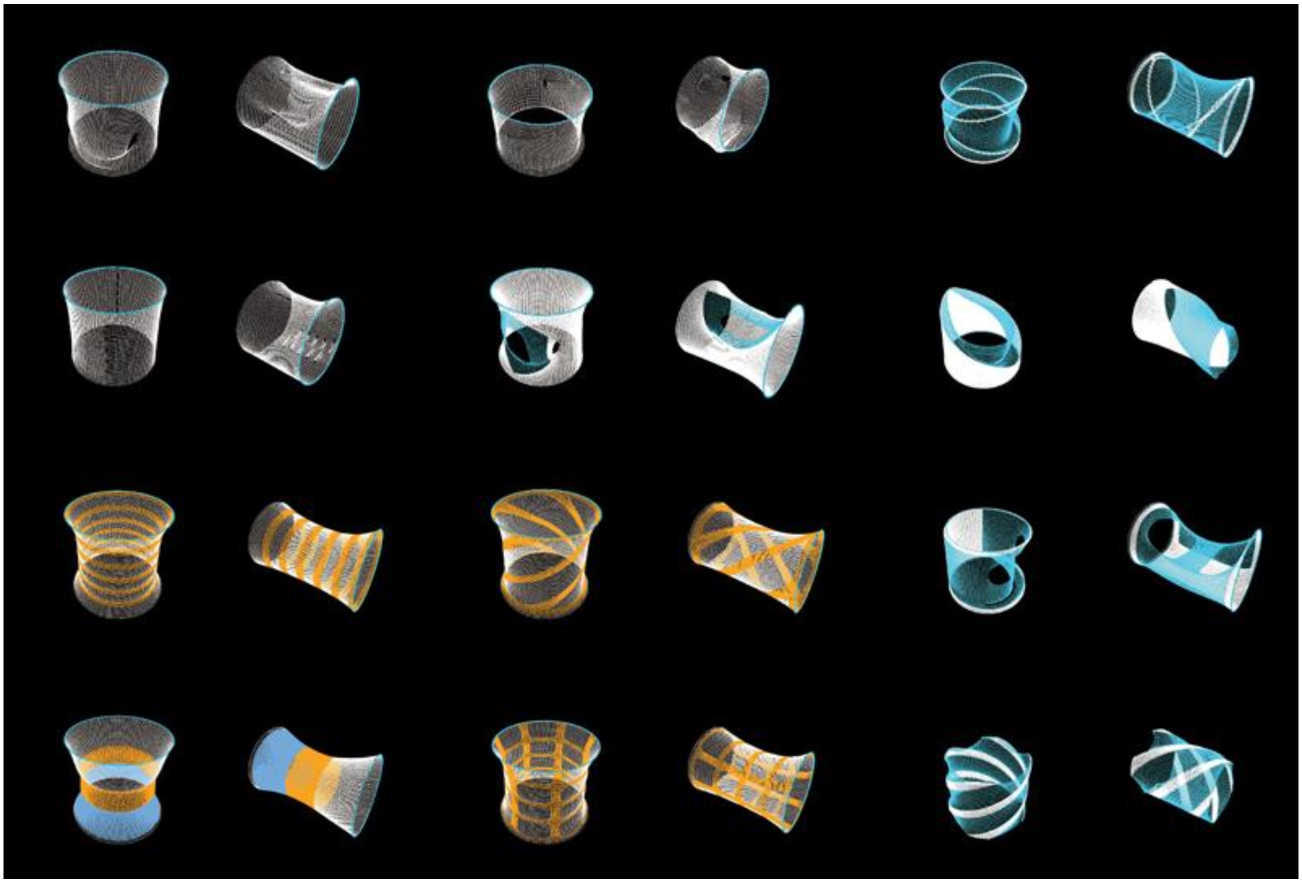
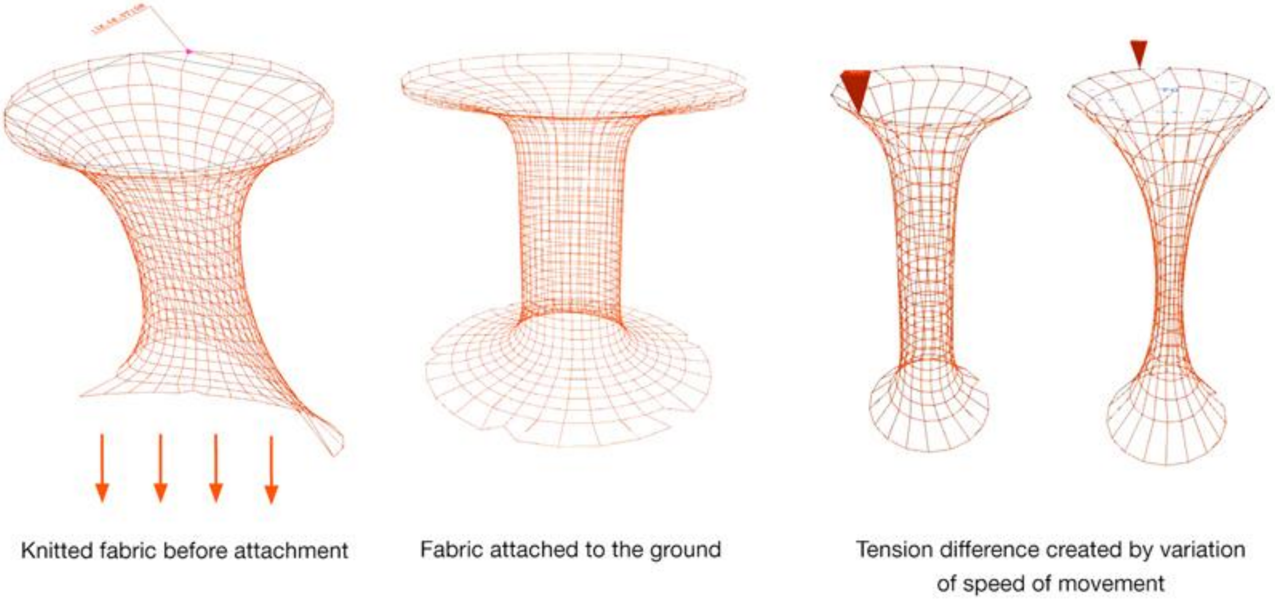


Figure 6. Material Versioning.

3.4. Machine Dynamics

In conventional knitting, the machine is stationary and the fabric is pressed under rollers and pulled down. In the conceptual machine, the machine moves up while knitting, gravity and ground are utilized to attach and tense the fabric. The following functions are used for simulating real time dynamics of the system.

- Fabric Attachment: This function allows attachment of the fabric to the ground or any other horizontal plane and the distance after which it attaches can be set on the interface. Here the first row of ‘particles’ on the needles of the machine are connected to corresponding points on the attachment plane.
- Machine Movement: This operation enables the machine to move vertically. The movement speed can be adjusted as per the tension required; a tight knit fabric would require a high speed and a loose knit fabric requires a slow speed.
- Tension: This is an absolute necessity for analogue knitting and is done using weights. In the digital system, the tension derived is a combination of machine movement speed and the friction caused by the attachment plane (Figure 7).



Knitted fabric before attachment

Fabric attached to the ground

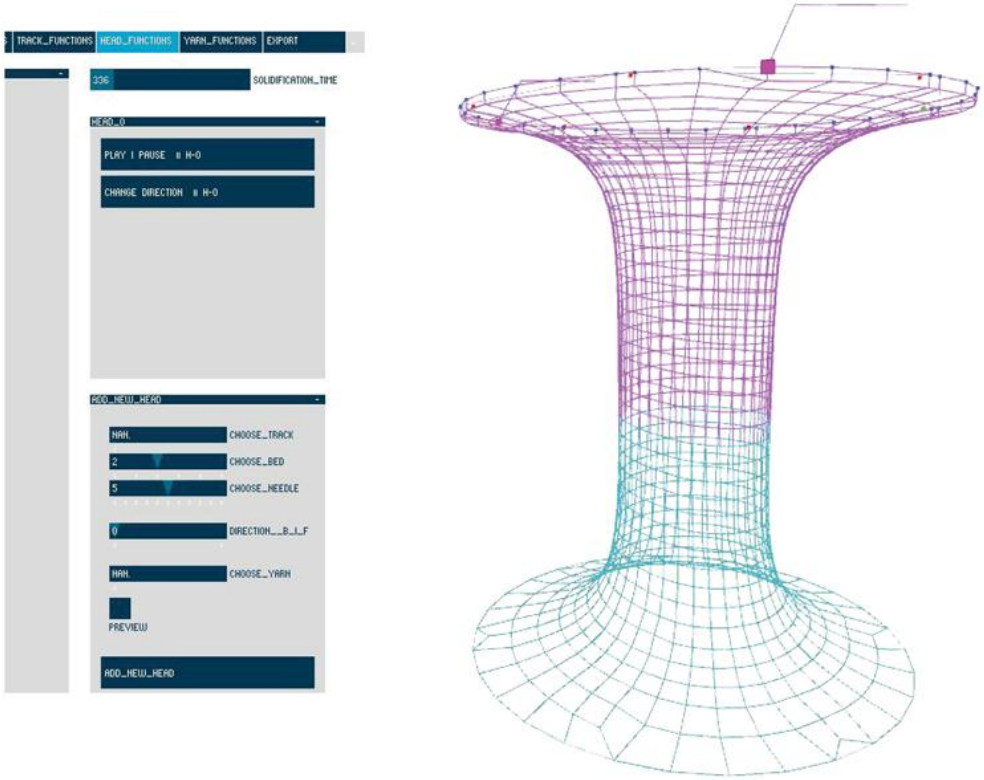
Tension difference created by variation of speed of movement

Figure 7. Machine Dynamics.

3.5. Materiality

The implications of knitting multiple yarns simultaneously were studied in analogue experiments. Being in the realm of fiber composites, matrix material for solidifying the yarns was used and eventually, the possibility of the fiber and matrix combination in a single material, i.e. the impregnated yarn, was explored. These were integrated into the simulation.

- Multiple Yarns: Each single yarn has selected properties, thus for combining multiple materials, the simulation creates a new material with a distinctive identity and combines the properties of the different yarns used.
- Solidification: This function imitates the machine and instigates the process of solidification of the yarn after it has been knit. For solidifying a knot, the simulation freezes the springs of the 'particles' involved.
- Impregnated Yarn: The knitted fabric can be soft and rigid, hence the digital system also needed the flexibility to selectively solidify a specific yarn and not all yarns. This way the simulation takes into account the structural impregnated yarns (Figure 8).



SOLIDIFICATION_TIME 336
CHOOSE_TRACK NAN.
CHOOSE_BED 2
CHOOSE_NEEDLE 5
DIRECTION__B_L_F 0
CHOOSE_YARN NAN.

Figure 8. Materiality – Knitted (magenta) and Solidification (blue).

4. Design Tool

After decoding the knitting action and all the parts of the proposed machine, the tool was used to design. Multiple heads were choreographed to knit along tracks and respond to bridges (Figure 9).

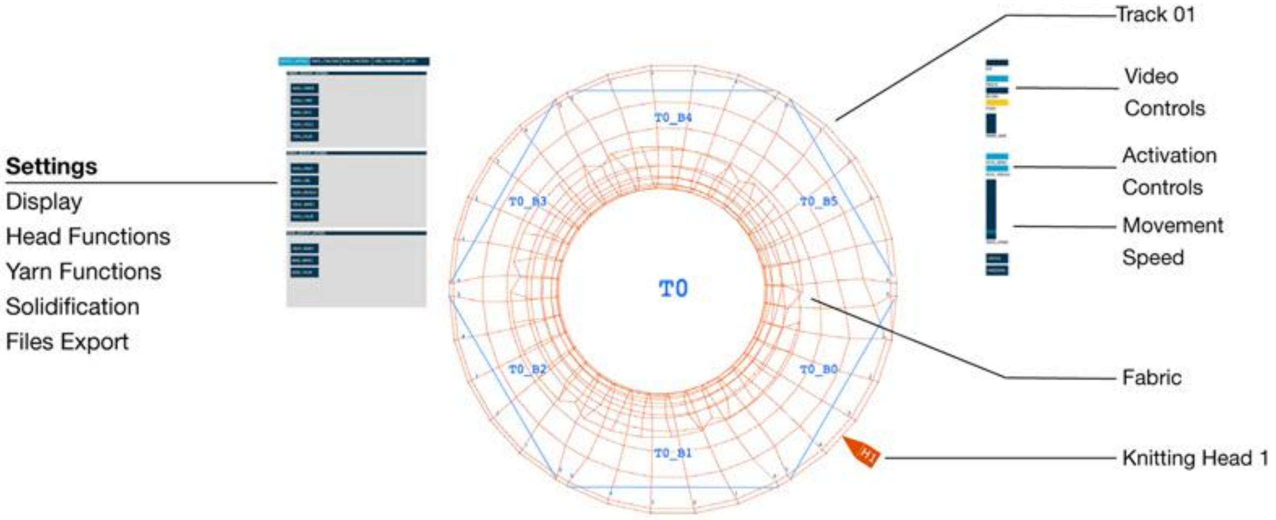


Figure 9. Digital Interface of Design Apparatus.

The yarn head carries the yarn and drops particles connected with springs along the track. Upon introducing the bridge function, the yarn head can move from one track to another. The bridge activation and routine can be predefined on the script or can be modified in real time on the interface. Routines of bridge activation – deactivation and bridge cross-bridge, facilitate in creating connections, bifurcations and topologies.

4. 1. Head Sequences

Further improvements in the machine design led to the deduction that the bridge was not required as a physical element, but rather as an action of the yarn head. At any connection point of two tracks in the hexagonal circle packing grid, the yarn head could perform any of the four prescribed actions. These actions are referred to as 'sequences'.

- Sequence 0: The 'sequence 0' is a command for the yarn head to bypass a connection point.
- Sequence 1: The 'sequence 1' for the yarn head to return back.
- Sequence 2: The 'sequence 2' for the yarn head to bridge.
- Sequence 3: The 'sequence 3' for the yarn head to cross-bridge (Figure 10).

It is important to note here that the 'connection point' connects two needles on one track, to two corresponding needles on the other track. So in sequence 2, the yarn head bridges two needles located in parallel, whereas in sequence 3, the yarn head bridges across two needles located in diagonal and stitches tubes together. Each yarn head can therefore be prescribed a routine of ‘n’ number of sequences and this routine can repeat endlessly.

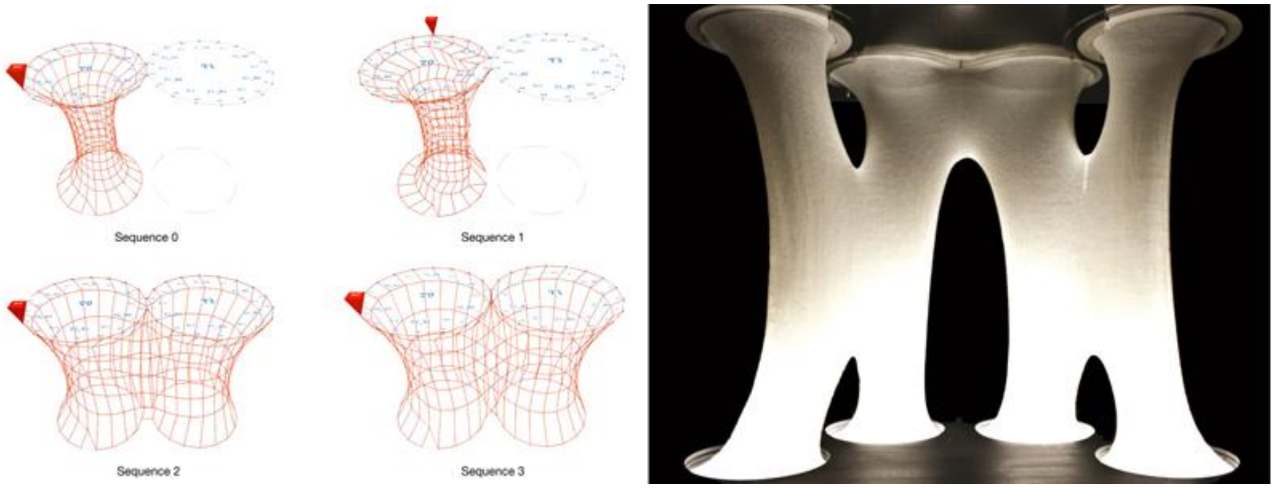


Figure 10. Digital Sequences and an Analogue Instance of Sequence Combination.

4.2. Yarn Head Initiation Point

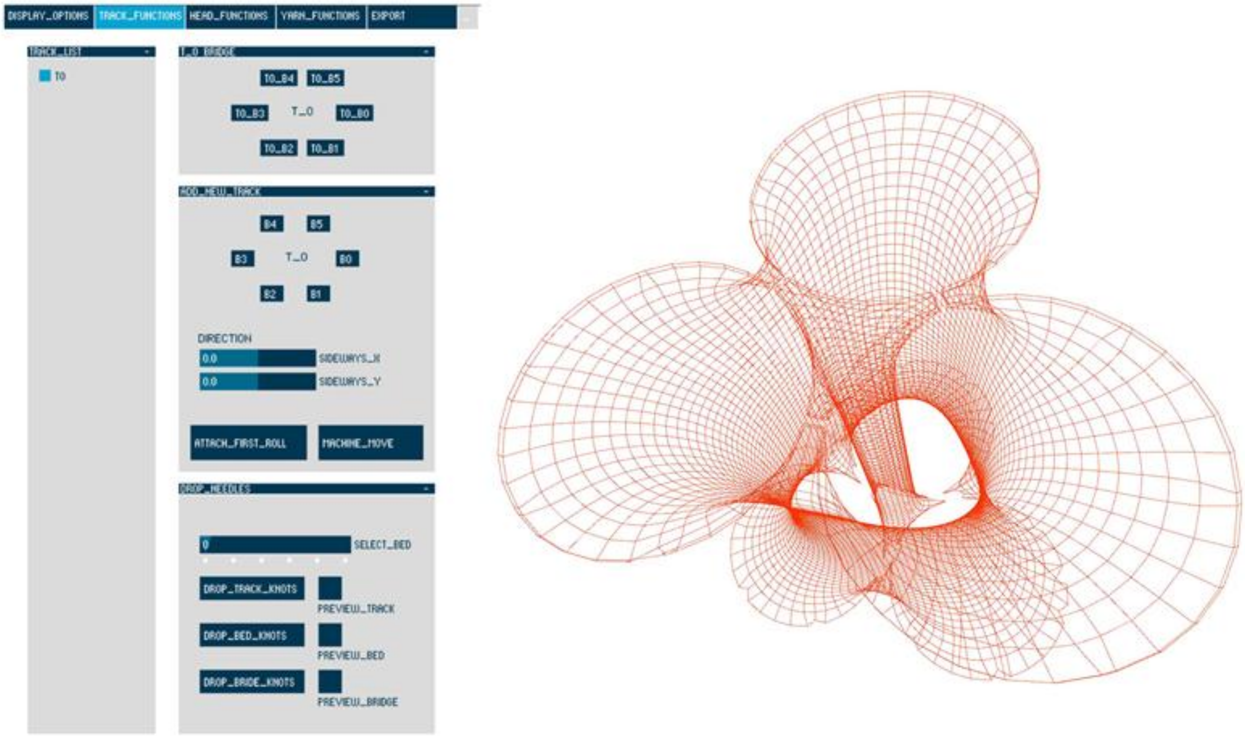
In a closed hexagonal grid configuration of three or more tracks, there is an external perimeter and an internal perimeter, enclosed within the tracks. The initiation point of the yarn head on the external versus the internal perimeter, can yield diverse results. The starting point of a yarn head can be directed, by giving it a track, needle bed and needle number location and also the direction of movement as clockwise or anticlockwise. As the yarn head path is prescribed by the routine of sequences, the knitted outcome is specific to the initiation point in the configuration of tracks.

4.3. Dropping Knots

The knit density can be changed and holes can be created by dropping knots from the needles. The idea of the digital machine is to experiment with topology and openings at an appreciable scale, so the focus was on dropping knots not for single needles, but for a group of needles. The simulation system offers the possibility of dropping a whole track or a certain needle bed of the track, or just the bridge as per the design prerequisite on the ‘track functions’ tab of the design interface (Figure 11).

4.4. Yarn Head Path and Number

As mentioned earlier, there is an external and internal perimeter enclosed within the tracks. These perimeters - the track itself (large perimeter) and the interstices created (small perimeter) - can both be employed as paths for the yarn heads. Interestingly, the speed of machine movement becomes critical here as time required for a cycle on each perimeter is significantly different, either causing the knit on the inside to be very loose or on the outside to be very tense. This can be countered by increasing the number of heads on the larger perimeter. The interstices give the opportunity to vary the enclosed knitted volumes and create structural elements, sub divisions or shafts (Figure 11).



SIDEWAYS_X 0.0
SIDEWAYS_Y 0.0
SELECT_BED 0

Figure 11. Dropping Knots Interface / Model with Variable Perimeters.

4.5. Attachment Control

Along with all the above functions in the digital system, the option to attach or not attach at any specific moment and the possibility to attach to the ground or another horizontal plane, opens up a new domain of topologies and morphologies (Figure 12).

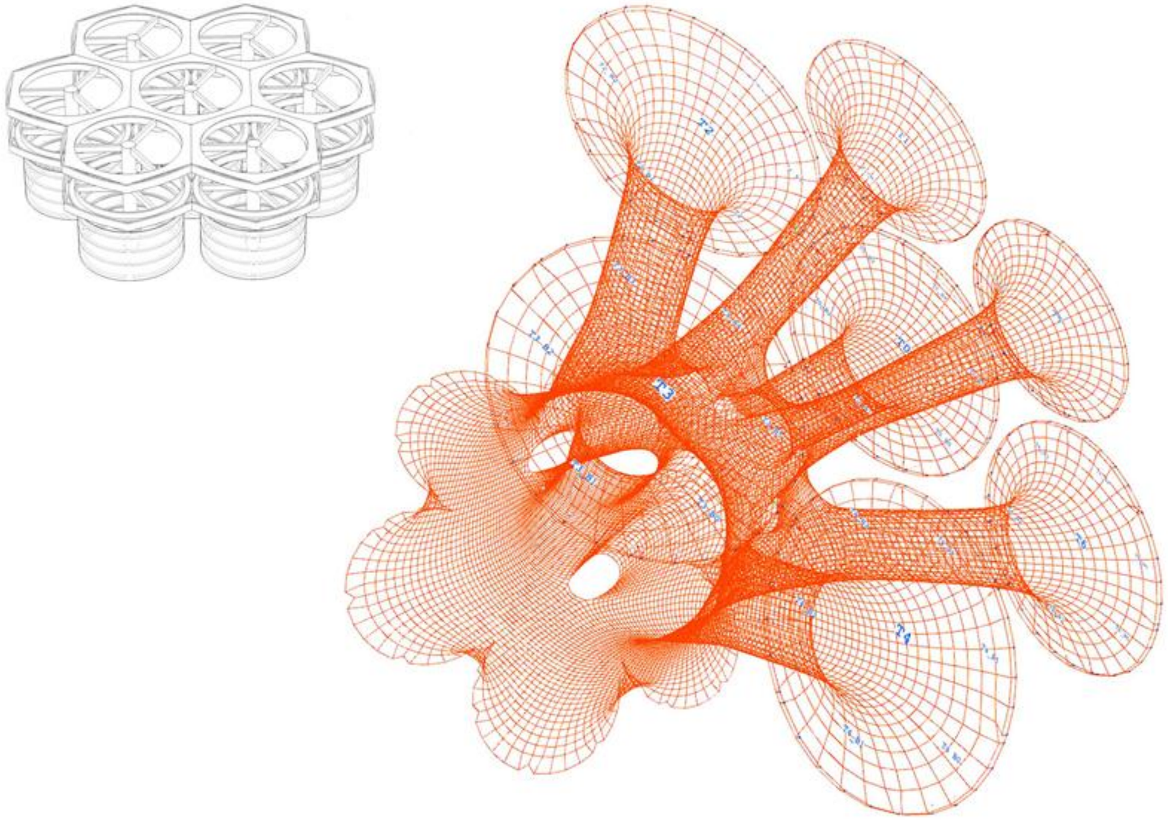


Figure 12. Seven Track Configuration and Possible Outcome.

5. Architectural Application

The design interface was developed from the understanding of analogue techniques, machinic systems and material behavior. The design tool contains all the knowledge gained from the decoding tool and imparts the opportunity to envision knitting as a principle of construction. The choreography of the heads determines the way the material is deposited and defines a new vocabulary for architecture.

The setup enables one to achieve complex topological surfaces as the machine has a one to one relationship to the material result and the natural local coordinates create a global- local structure. Additionally, to address macro level and micro level issues with the system, the idea of a machine of variable sizes within the hexagonal grid was introduced, hence imparting it the capacity to integrate multiple scales, resolutions and functions. The tectonic aspects are addressed at two levels by the system, firstly at the spatial or programmatic level, providing space, structure and punctures, and secondly at the performative level, providing micro infrastructure, embedded services and performative skin (Figures 13a, 13b and 13c).

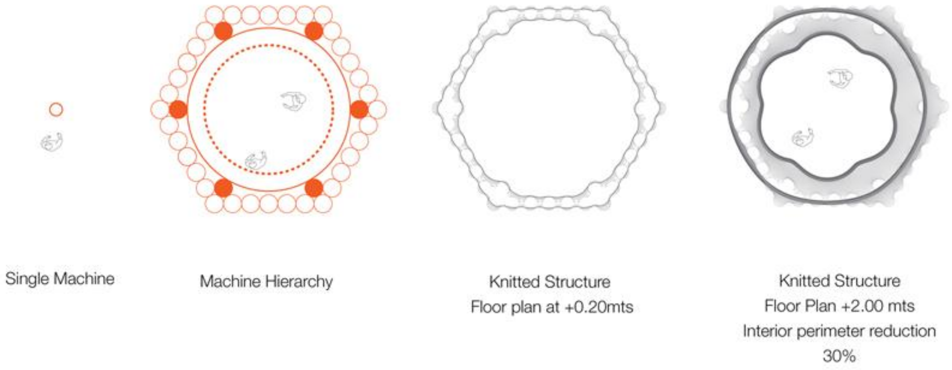


Figure 13a. Size and Hierarchy of Machines.

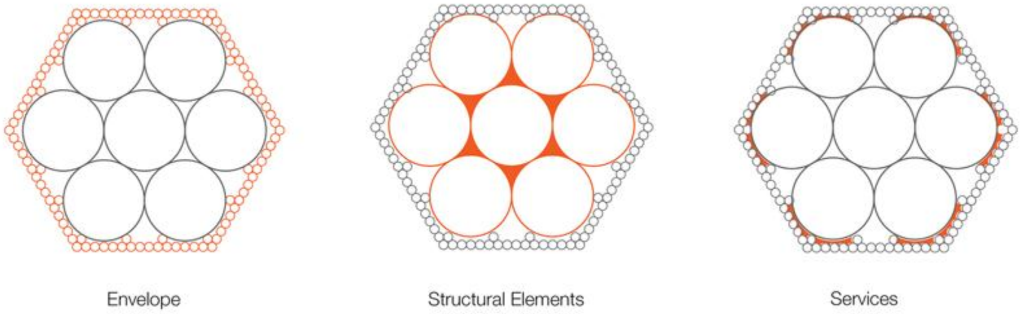


Figure 13b. Resolution and Relationship to Tectonic Elements.

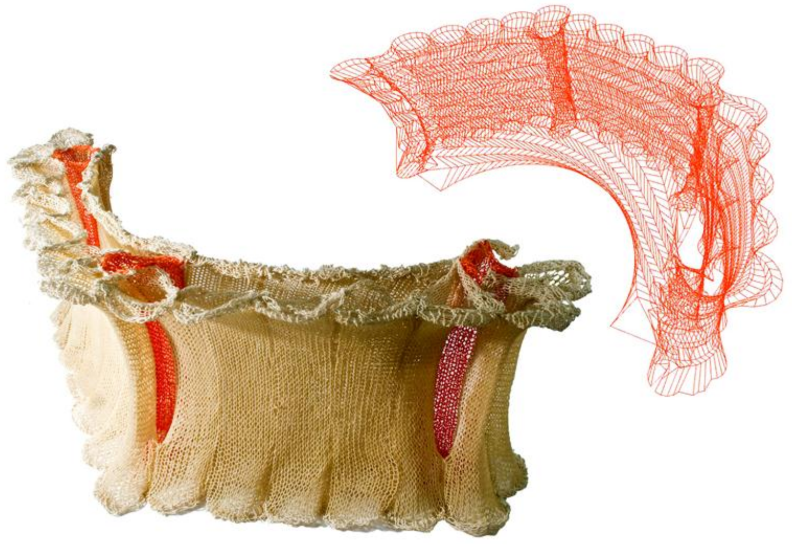


Figure 13c. Analogue – Digital Relationship of Tectonic Elements.

The system was analyzed to appropriately locate the application of the reinterpreted method. Being multi-scalar, modular and collaborative, it has the potential to attend to various scales, programmes and sites and can adapt to site constraints with the flexible deployment and material usage approaches available. The nature of the system establishes its prototypical application in the realm of quick deployment, minimal impact and integrated mono-system. The multiple interconnected layers give the opportunity to embed micro infrastructure and services into a unified structure, making it suitable for macro level infrastructure.

For testing the system, the infrastructure development for a new transport technology - Personal Rapid Transit (PRT) system in the city of Bath - was chosen as the application scenario. The aesthetics, lightness and transparency of knitted fabric, aptly situate it in the deep rooted culture of textiles in England's historic towns. The PRT system demonstrates resonance to knitted topologies with the proposed machinic system for its concepts of continuity/ bifurcations, networks/ nodes. (Figures 14a and 14b)

Figure 14a. Architectural Application / PRT Station Canopy in Bath.

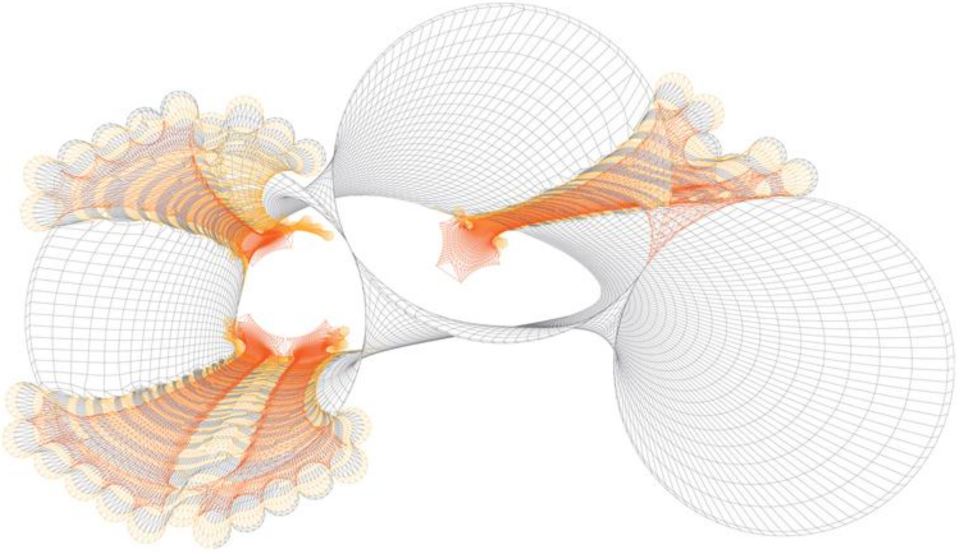


Figure 14b. Roof Plan of PRT Station Canopy, Demonstrating the Design Tool.

Different sites where the PRT infrastructure extends into other civic infrastructure were selected in order to explore the prototypical nature of the system on the basis of programme, scale, context, machine configurations and material (Figure 15). Though all sites use the same system, the design and deployment approach to each varied, thus testing and demonstrating the feasibility of the system and also defining its limits and ranges.

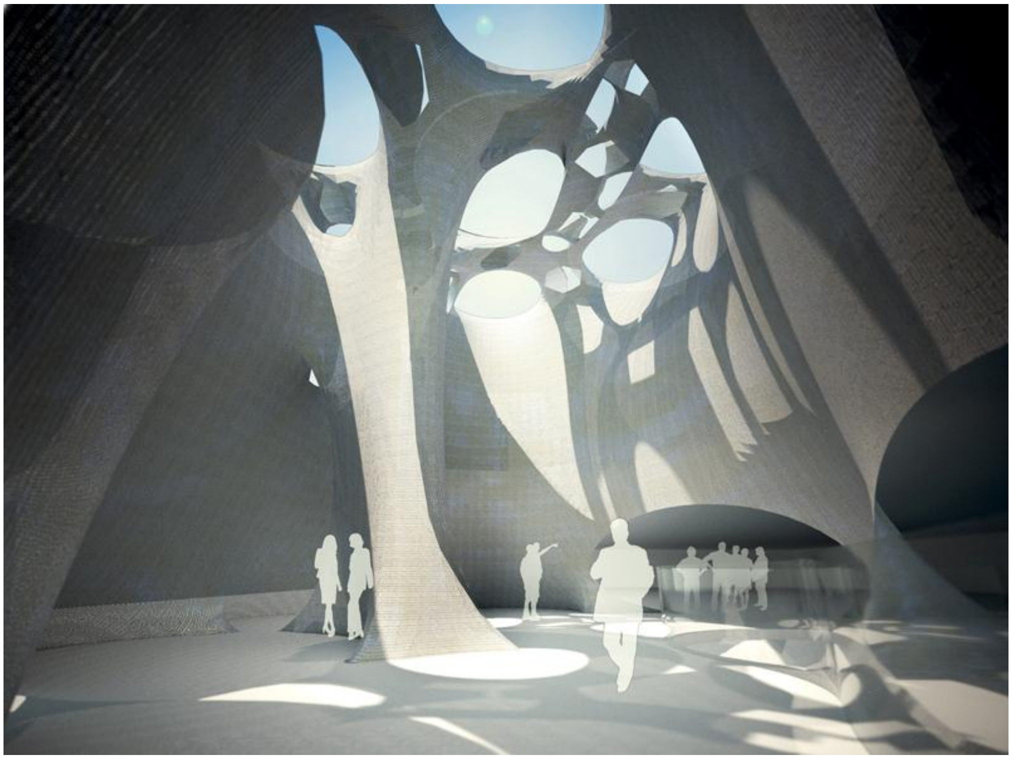


Figure 15. Application / Art Museum and Underground PRT Station in Bath.

6. Generative Tool

The design tool thus facilitates in realizing most of the tasks dealt with in conventional materials and machines in architecture. The digital machinic system offers several set up options, in terms of the number of tracks, their configuration, bridge connections, number of yarn heads, their start point and the yarn type used. Along with the attachment, movement and solidification control and most importantly the sequences prescribed to the yarn heads, the permutations and combinations possible are endless.

The system provides multiple solutions with equal suitability, thus making it extremely complex to solve in a linear manner (Alfaris and Merello, 2008). In order to locate appropriate architectural solutions, only a generative system would be capable of evaluating, selecting and optimizing architectural requisites.

The third tool - generative algorithm - was a modest attempt to generate populations of valuable architectural solutions from the proposed machinic system on the basis of structure and space. With enhanced sophistication and precision, the procedure could be an objective optimization tool and in the future could be extended to other physical and performative parameters like openings, heights, surface resolution, layering etc.

To understand generative systems, Anad Alfaris and Riccardo Merello's paper *'The Generative Multi Performance Design System',* presented at the ACADIA 2008 was referenced. The paper proposes a framework to generate solutions within design space defined by the system's design language, with the integration of various performance criteria. The system is composed of four phases, namely, synthesis, analysis, evaluation and optimization. Within these cycles, modules store parameters, constants and constraints. To test the feasibility of a generative system by comparing different iterations to find the most optimum, these cycles were applied to the digital machinic system.

- Synthesis: The basic architectural parameters of structure and space were established as the design intentions.
- Analysis: Since the forces of gravity and pull on the knitting machine control the fabric, the structure is characterized by the tension in the knots. The space is embodied in the dimension of the enclosure created.
- Evaluation: To understand the stretch in different regions and the cross- sectional changes in the knitted fabric along both axes, analogue models were studied.

Computationally, for structural evaluation, the system measures the tensile forces (spring strength in comparison to the rest position strength) acting on each knot and categorizes them to be: over stretched, under stretched and ideally stretched, on the basis of analogue calibration models. In proposed simulation, ideal stretch is typified with green color, maximum under stretch with blue color and the moderate stretch situation with yellow. The red color depicts maximum over stretch possible, beyond which the spring is at breaking point and hence unsuitable, shown in black.

From analogue models it was also concluded that a knitted fabric typically stretches up to a third of original length. Considering the self organizing behavior of knots, the implication of the increase in length is visible in the reduced cross section of the tube. Thus for spatial evaluation the minimum dimensions for a habitable space were established based on the machine size and the percentage decrease in cross section after stretching, and the options were evaluated against that minimum dimension, discarding infeasible options (Figure 16).

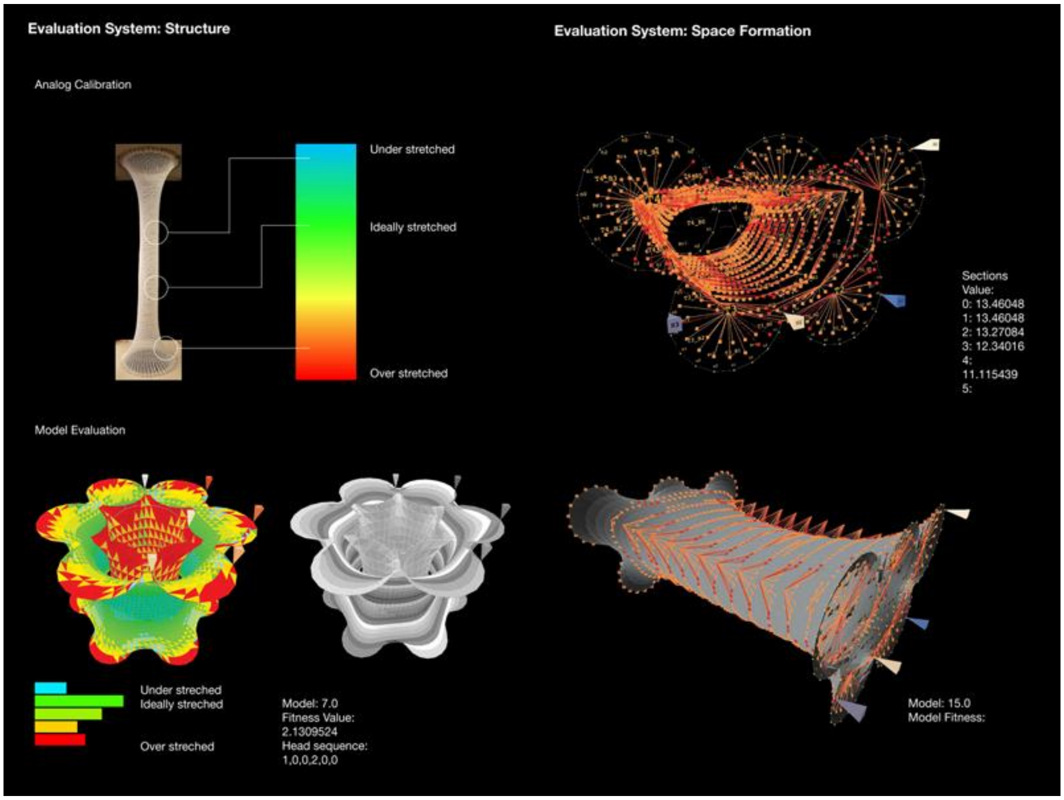


Figure 16. Evaluation Parameters of Structure and Space.

- Optimization: Typically the most optimum solution could be chosen by comparing it against the ‘predefined best solution’. But the proposed system has no preconceived ideal solutions, thus creating the challenge to locate the most optimum solutions through a series of generations.

‘Evolution starts from a population of randomly generated design solutions to guide the evolution. The purpose is not to produce a global optimum solution, but rather to direct the

> evolutionary process to produce populations of good solutions' (Alfaris and Merello, 2008). This evolutionary algorithm can be decomposed into five stages: fitness function, selection mechanism, coupling, and mating and mutation introduction (Rutten, 2010). Applying these principles to develop an optimization tool, the constants or the chromosomes were set with respect to track configurations and yarn head locations. The first population of one hundred iterations was then generated by random combinations of sequences 0, 1, 2 and 3 (0 = continue, 1 = go back, 2 = bridge and 3 = cross-bridge) which are comparable to the genes or the DNA in biological evolution.

The iterations were evaluated against the parameters of structure and space and assigned a fitness value. For structural evaluation, fitness is determined by the number of ideally stretched knots, with a positive weight value and the number of under and over stretched knots, with a negative weight value. These were then averaged to get a fitness value. Similarly, for spatial evaluation, the distance of 'space cells' on each segment of the surface from the central axis is measured against the ideal prescribed distance and then averaged across the entire envelope.

Of the hundred iterations, ten iterations with the highest combined structural and spatial fitness value are selected as the best. Each of these then mates with the other ten iterations, to generate the offspring of the second generation. This process is repeated for ten generations. Interestingly, the resulting ten iterations tend to become self similar by the seventh generation (Figure 17).

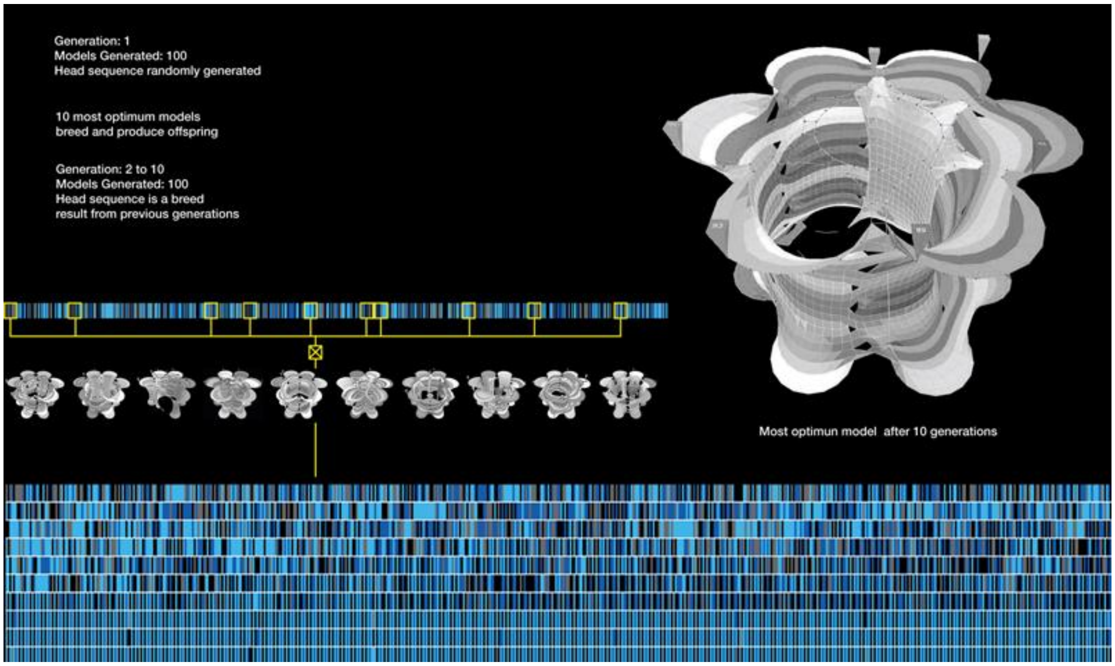


Figure 17. Genetic Algorithm Developing Iterations over Ten Generations.

7. Conclusion

A constructed fibre articulates surface and layering, as trajectory of a single line gives one/ two/ three dimensional geometry - Self- similar and repetitive, loops bind and string seamlessly - Local rules define a language of assembly that yields dynamic global results - A mute material becomes mutational. Such is the richness of a simple household craft.

The pre- designed technique through pre- programmed instructions on the jacquard loom, gave way to computation. With an on-site fabrication machine, inspired by a household technique, which gets feedback from materiality and responds to it, the three tools of the proposed system use computation to design, visualize, instruct and fabricate in real-time.

'Knitectonics' is our humble effort at the re-interpretation of an existing technique and machinic system to articulate novel architectural design processes. Our attempt, in a limited capacity, has been to explore diverse issues of machinic systems, materiality, deployment, topology, layering, scale, parametrics, algorithms etc.

Contemplating a future for the project, there are various potential concerns to focus on. As mentioned earlier, genetic algorithm is a possibility as an objective optimization tool, but in isolation of a number of subjective concerns. We recognize that the evaluation parameters of the algorithm require enhanced sophistication and precision and also technical inputs from specialists. Another pragmatic approach could be to build a working prototype of the machine in order to appreciate the structural potential of the technique and get feedback from materiality. This could potentially present a pristine stratum to exploit fibre composites in architecture.

The vast world of textiles – techniques, materials, processes, machines etc - is a rather intimidating world. For the sake of simplicity, we had defined a small and precise set of working tools with respect to the technique of knitting. The stitch we considered here was interlooping, on a circular weft knitting machine. The surface consistency can be interrupted by utilizing different stitch types and topologies variations can be created by increasing or decreasing the knot size (tuck stitch and rib stitch). Applying principles of warp knitting machines could escort us to the realm of high strength 3d spacer fabrics. We could thus expand the technical tool set and study the systemic implications.

Turing proposed the concept of 'computation' based on binary notations and intended the 'universal machine' to represent function of any existing machine and thus the question of extending the idea of notation into our computational system and directly using the machine. We see opportunity in the idea of the notation in translating our digital commands to a physical machine, similar to the code used by the contemporary flat bed knitting machines. Our preliminary effort at using algorithmic routines was in sequencing the movement of the yarn head on the needle bed, but can be continued to individual needles; and further widened to stitch matrix taxonomy that organizes stitches according to spatial qualities like enclosure, transparency and interdependence etc.

Since our machinic system is a tension based system and knitting has a self- organizing behaviour, all the resultant surfaces created are minimal surfaces. The issue of surface and geometry could be explored beyond the family of minimal surfaces, possibly by subjecting the knitted fabric to additional loads, pressures, strains, deformations. For instance, the knitted structure could be treated locally and non- uniformly during the streamline machine process, by using the possibility of differential attachment or solidification. The machine and the material output have had a direct relationship for us, but we appreciate the potential of 'controlling material' as opposed to 'self- organization' alone.

Another idea is to investigate the application of our machine as a system to fabricate individual architectural components that can then be organized together to form a whole and not the structure in totality.

It is interesting to note that the aesthetics were derived from the functional aspects of the design, which in turn were deduced from the technical logic of construction system. Thus the 'process of making' was as 'the DNA of the creation', where quantitative pursuits become qualitative.

These are the first steps in the research and development of a knitting-based digital parametric system that enables real-time fabrication to intelligently interact with the parameters, propose an 'optimized solution' bracket within which a designer could create and communicate a design to the deployment machines (Figure 18). **But most importantly, this parametric process of decoding, designing and generating, could be utilized with any other machinic process to develop novel fabrication methods for architecture.**

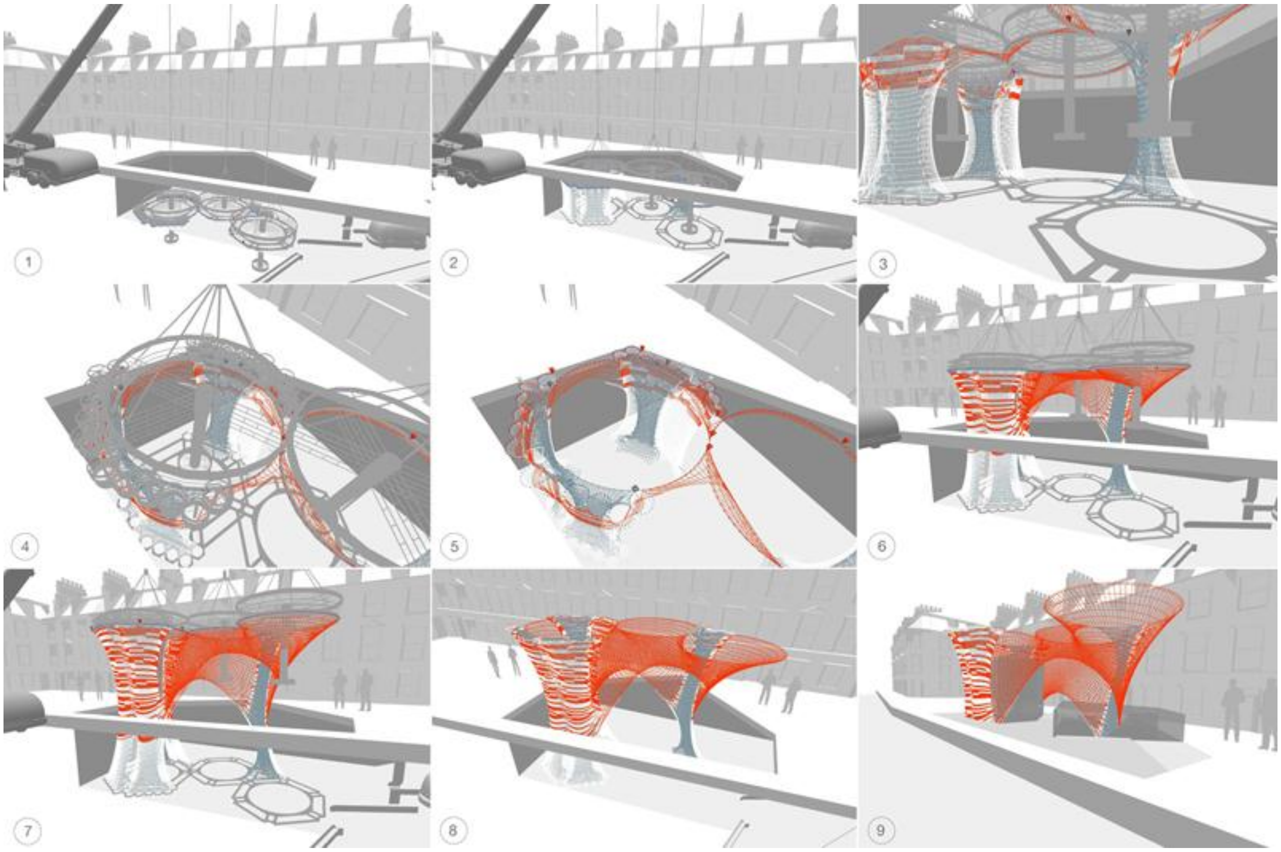


Figure 18. On-site Deployment Process Using Knitting Technique.

References

Alfaris, A. and Merello, R., 2008. The generative multi performance design system. *ACADIA*, pp. 449-455.

Baurmann, G., 2010. *Crocheting algorithms.* Available at: <http://aap.cornell.edu/events/upload/baurmann_abstract.pdf> [Accessed 26 January 2011].

Chisom, M., 2011. *The Jacquard loom: its history, development & relationship to computers.* Available at: <http://gernot.xarch.at/weave/article_about_jacquard.html> [Accessed 24 February 2011].

Frey and Reas, n.d. *Processing software.* Available at: <www.processing.org> [Accessed 10 February 2010].

Malé-Alemany, M., 2009. *Machinic control: studio brief 2009-10. Design research lab*, *volume 13 (Proto Design).* England: Architectural Association.

Manini, B. 1993. 'Knitting Machine for Producing Tights', United States Patent, Number 5,226,297.

Rutten, D., 2010. *Evolutionary principles applied to problem solving.* Available at: <http://www.grasshopper3d.com/profiles/blogs/evolutionary-principles> [Accessed 21 September 2010].

Schmidt, K., n.d. *Toxi libraries for processing.* Available at: <www.toxiclibs.org> [Accessed 6 October 2010].

Semper, G., 1989. *The four elements of architecture and other writings.* England: Cambridge University Press.