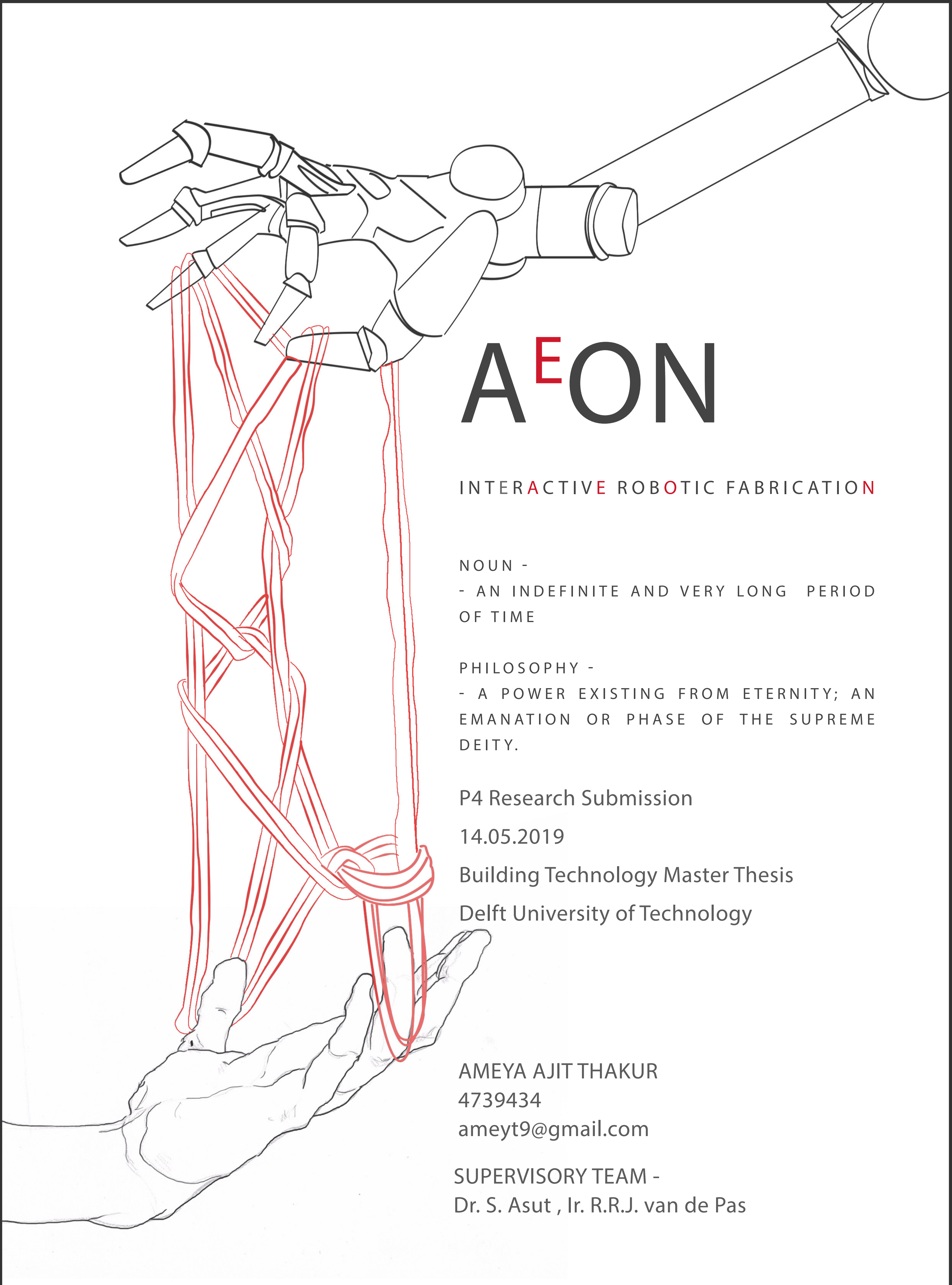


AEON

INTERACTIVE ROBOTIC FABRICATION

NOUN -
- AN INDEFINITE AND VERY LONG PERIOD OF TIME

PHILOSOPHY -
- A POWER EXISTING FROM ETERNITY; AN EMANATION OR PHASE OF THE SUPREME DEITY.

P4 Research Submission

14.05.2019

Building Technology Master Thesis

Delft University of Technology

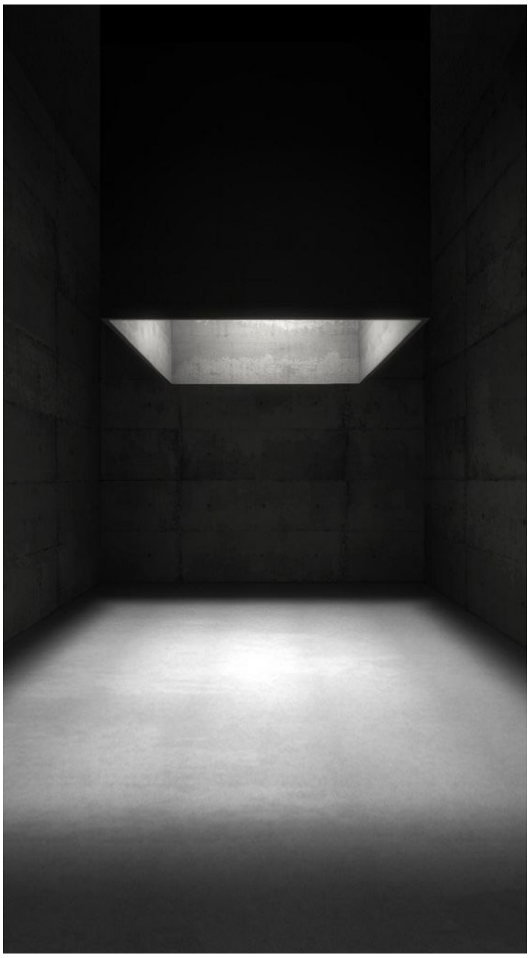
AMEYA AJIT THAKUR
4739434
ameyt9@gmail.com

SUPERVISORY TEAM -
Dr. S. Asut , Ir. R.R.J. van de Pas

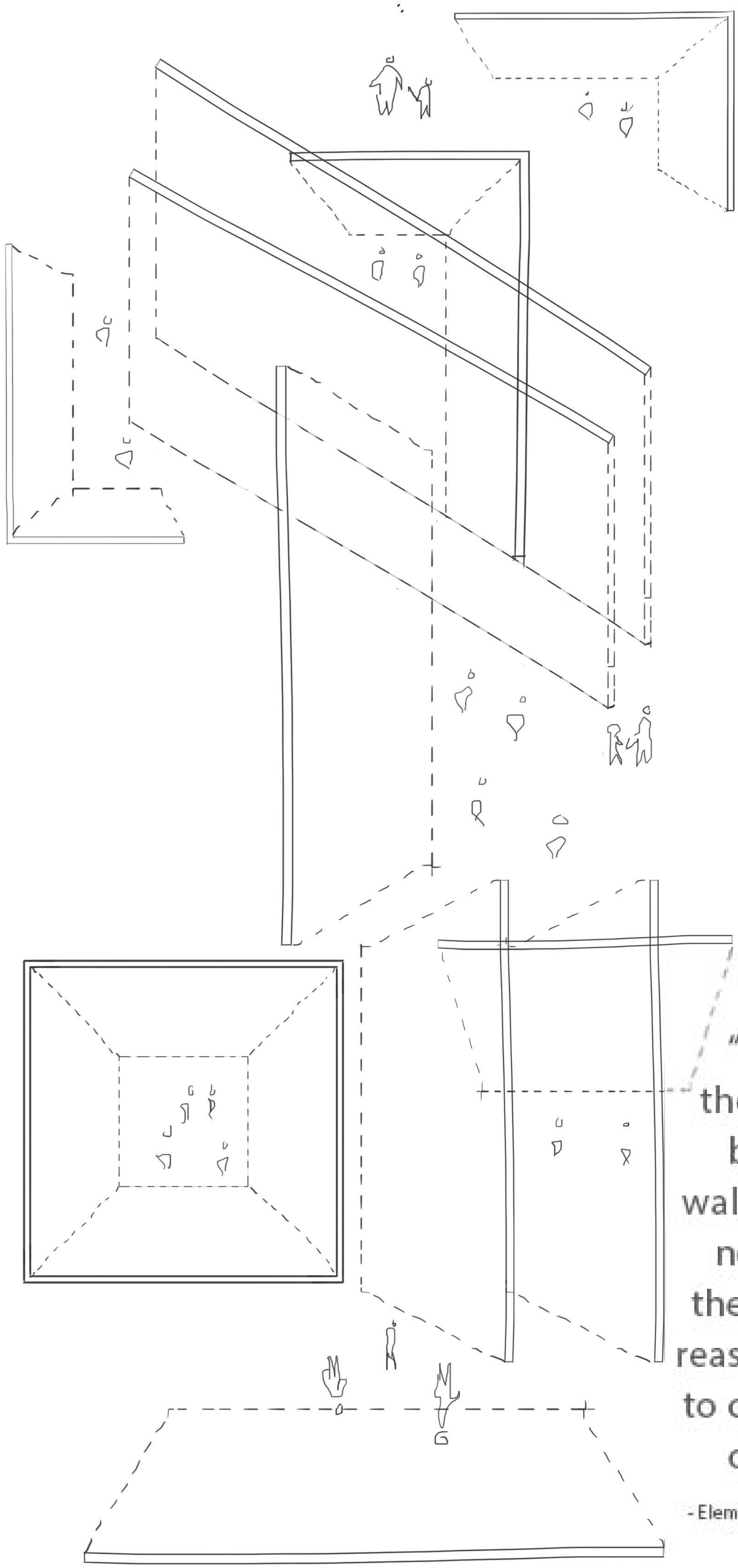
Content

Background

Today's technological culture with its mass-produced easily maintained, seducingly new building materials enhances and supports mere visual aesthetics, the immediate gratification of only one of our senses – "The Eye" – is achieved. This exclusion of other sensory realms ignores brutally the essential need of the human body in this alienating, sterilized process of building, such as intimacy, nearness, touch, and much more (H.Kukelhaus, 1972). The culture of building information modeling has led to a very mundane process where the architect is completely detached from the fabrication process, because of this our senses are subdivided rather than enhanced through our built environment. The computer as an invention is solely beneficial to liberate the fantasy of human while facilitating effective design work. Our magnificent, multisensory, synchronic and simultaneous capacities of imagination are flattened due to computer imagining, resulting in a passive visual manipulation of a design process which facilitates only retinal senses alienating the body as a whole from architecture (J. Pallasmaa, 1996). This calls for a collaborative approach where the architect is not behind the screen but is inside it, manipulating and molding the design as he feels fit.



Temple house by Willam Weaver.
Image soure - Pinterest



"For the architect the space or the gap between ground, walls and ceiling is not nothingness, quite the contrary: the very reason for his activity is to create the hollow in order to contain."

- Elements of architecture for place to place, Pierre von meiss

Figure 1

1.Introduction

The phenomenon of visual dependency is not new, there has been research and studies which talk about a collaborative approach between digital fabrication and designers to develop spaces which are not detached from other sensory feelings, Interactive techniques in digital fabrication developed as a result of extensive research conducted by the HCI community show a potential promise. (B. Lafreniere et al, 2016). Construction and architecture are now being integrated with robotics creating a symbiotic relationship between these different fields where they push each other's outer boundaries to create new modes of design construction using these technological advances.

A range of compelling and interesting studies to integrate robotics and architecture has been quite evident in this era, this research on an approach which collaborates robotics and architecture for digital fabrication and construction industry is not recent(N.Vazquez, W.Jabi, 2015), one of this research focuses on the potential of integrating traditional weaving with robotics. As weaving process is more human-centric where the weaver guides the tool to achieve the desired pattern, integrating this method with robotics and HCI may lead to a collaborative design process where the designer guides the robotics system to develop build spaces which are more coherent with the context and are solely not depended on visual aesthetics.

Integrating Human-Computer Interaction (HCI) and weaving offers an opportunity to develop built spaces which are not only visually pleasing but also invokes different sensory feelings, as fabric weaving is a tactile medium which can be molded into various forms which in turn combined with the haptic inputs from the designer and precision of robotics system can lead to developing building elements which have never been explored before.

This thesis examines the potential of using tangible interfaces, sensor feedback, and HCI to develop an intuitive design and construction process utilizing robotic weaving. Robotic weaving and HCI offers the element of tactility and tangibility which can enable an adaptive fabrication process, in which a user can easily and quickly create various design combinations by forming individual architectural elements which weave or interlock together into an overall system. To prove the thought of this concept, a design problem focusing on built space will be tackled particularly focusing on developing a variety of architectural elements which are to be weaved or interlocked together to form living spaces, ultimately developing a robust and open-end design and construction strategy for HCI and robotic weaving.

Figure 3, Image soure - google.com

"Our bodies and movements are in constant interaction with the environment; the world and the self inform and redifine each other constantly "- The eyes of the skin,Juhani Pallasmaa.

1.1 Problem statement

Architecture is experienced in a multi-sensory way. A work of architecture which is designed or considered only from the exterior ceases to be architecture and becomes a mere object. However, the use of digital tools and computer imagining focuses mainly on the visual aesthetics of architecture. This visual dependency could be the result of a disconnect between the designer and the fabrication process, to bridge this gap between the two actors a variant method could be adopted which incorporates intuitive design capabilities of the user and the precision of digital fabrication process. There are few studies which investigate the possibilities of integrating HCI and digital fabrication to develop a new process in architecture design and construction industry.

1.2 Research question

How can robotic fabrication and human-machine learning inform the design process to develop architectural elements for a built space which incorporates both the intuitiveness of the designer and precision of digital fabrication?

1.3 Objective

The research objective is to investigate possibilities of combining HCI with robotic weaving by designing architectural elements for a built environment, developed in a collaborative environment where the designer informs the digital fabrication process and vices versa.

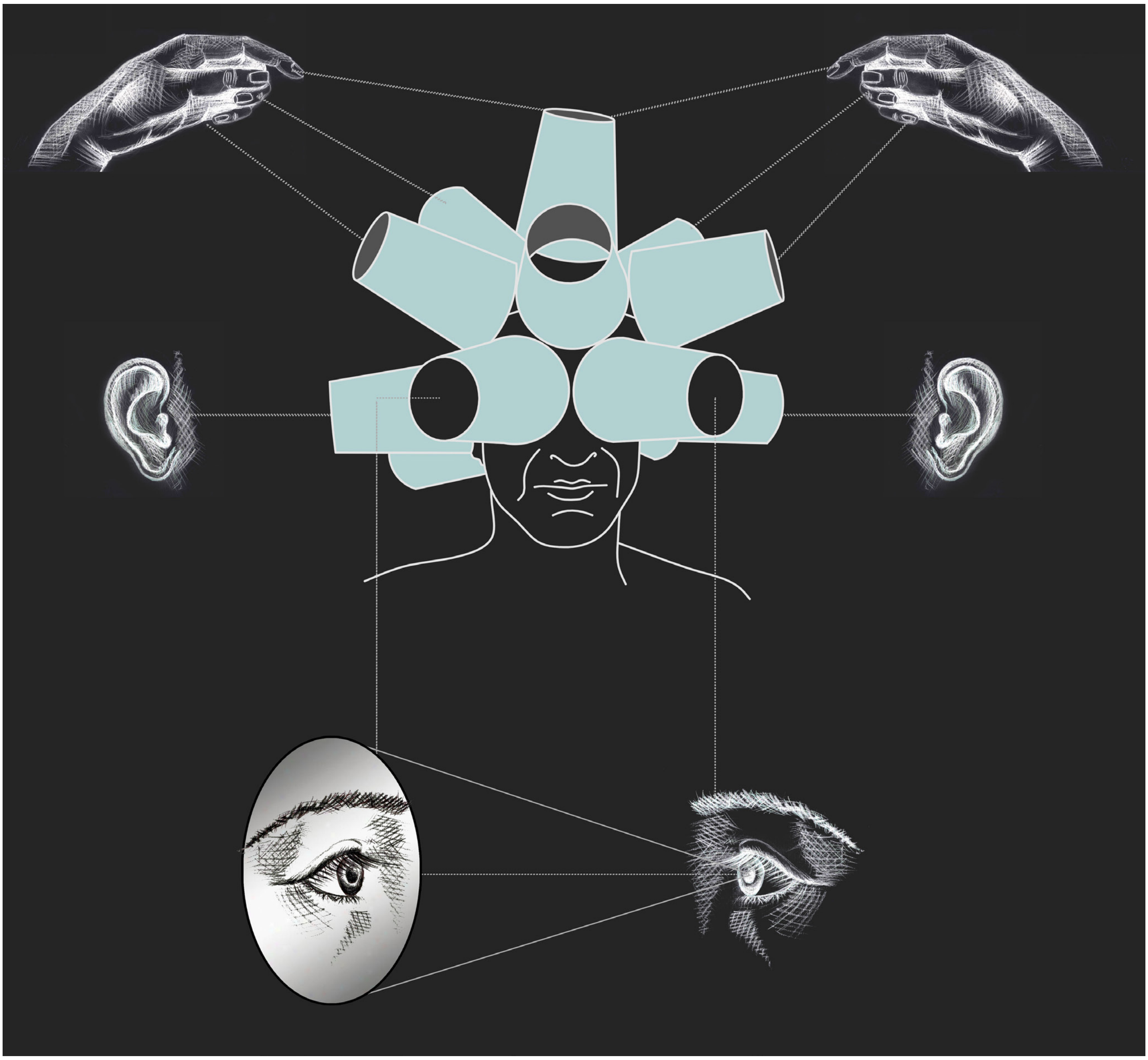


Figure 3, Illustration by Zarya Vrabcheva.

2. Decoding non – visual essence of architecture

Architecture is more than just visual aesthetics, built spaces are meant to involve and move an individual in a way that his body remembers the essence of the space and engraves its spatial quality into his memories. According to writings of P. Zumthor architectural elements are meant to continue evolving as any biological being undergoes evolutionary organic processes, build space is meant to radiate this evolutionary process in a way that is challenging an individual who confronts it and forces him to detach from himself, which may result in going beyond and directing this feeling into something uncontrollable. This building built on such phenomenology always conveys an intense feeling of their spatial quality while also leaving a strong impact. This mysterious void called space is then embraced by this feeling making them vibrate in a special way (P. Zumthor, 1998).

We experience that the dual nature of the visual field is united by a trick of the eye which relates what is at hand (the object) to what is eternally unavailable (the horizon). Thus a concept of space emerges in which the duality of the plane turns into the unity of the 3-D space of the physical world (H.Kukelhaus, 1972). Our Sense of reality and self of being-in-the-world is and strengthened and articulated by architectural experiences; it detaches us from the worlds of mere fantasy and fabrication (J. Pallasmaa, 1996). Several realms of sensory experience fuse and interact together to create a spatial sense, the German term "Gestalt" defines correctly what architecture of build spaces is supposed to represent – an organized whole that is perceived as more than the sum of its parts. The role architecture plays in human life is indiscriminately important as it is created to embody the lived existential metaphors and define the world around us.

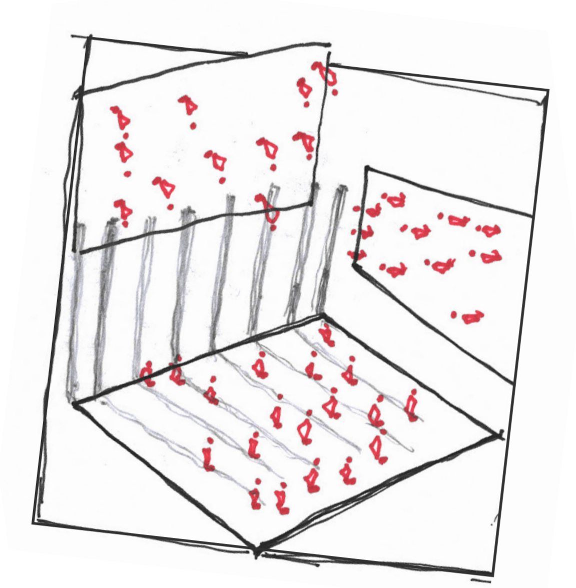


Figure 4

2.1 Blind and disconnected

Theorist and architect Bernard Tschumi (1975) suggested that the mental world in which architects design and the physical world in which they build are disconnected. (J. Herssens, A. Heylighen, 2008). The emphasis on visualization has increased as a result of our cultural history: on one hand because western society is marked visually; on the other hand, because of master builder status of the architect (Goldsmith 1997). This gap could be traced back to the fact that while designers have the ability to imagine and create spaces on paper when it comes to concretizing the idea most of these concepts are lost as the designer is not involved in the final fabrication process and thus loses his status as the master builder. Ignorance in field of peripheral vision is one of the reasons why urban and architectural settings of our time make us feel like outsiders, in comparison to natural and historical settings which engages in a forceful emotional spatial sense. Spatial and bodily experiences are transformed into retinal gestalt due to this unconscious peripheral perception, this perception integrates us with space, making us mere spectators, while pushing is out of the space due to focused vision (J. Pallasmaa, 1996).

2.2 Touch as a sensory vision

Aristotle, in order to prove that skin is an active organ, suggested a little experiment, rub your finger and thumb together in a clockwise direction, soon you will notice something strange. As if there's a small spherical, granular object between your hands, thus he wanted to prove that skin's sense of touch coincided with its ability to create something. In other words, the skin creates tangible facts (H.Kukelhaus, 1972). This complicated organism called Hands are the sources of delta in which all the life flows together creating a great surge of current action (J. Pallasmaa, 1996) Our 'sense of comfort and wellbeing' in a built environment is a result of our tactile experiences which is also used for orientation. We can move or reform objects, change our environment based on our tactile sense(D. Arets, 2015).

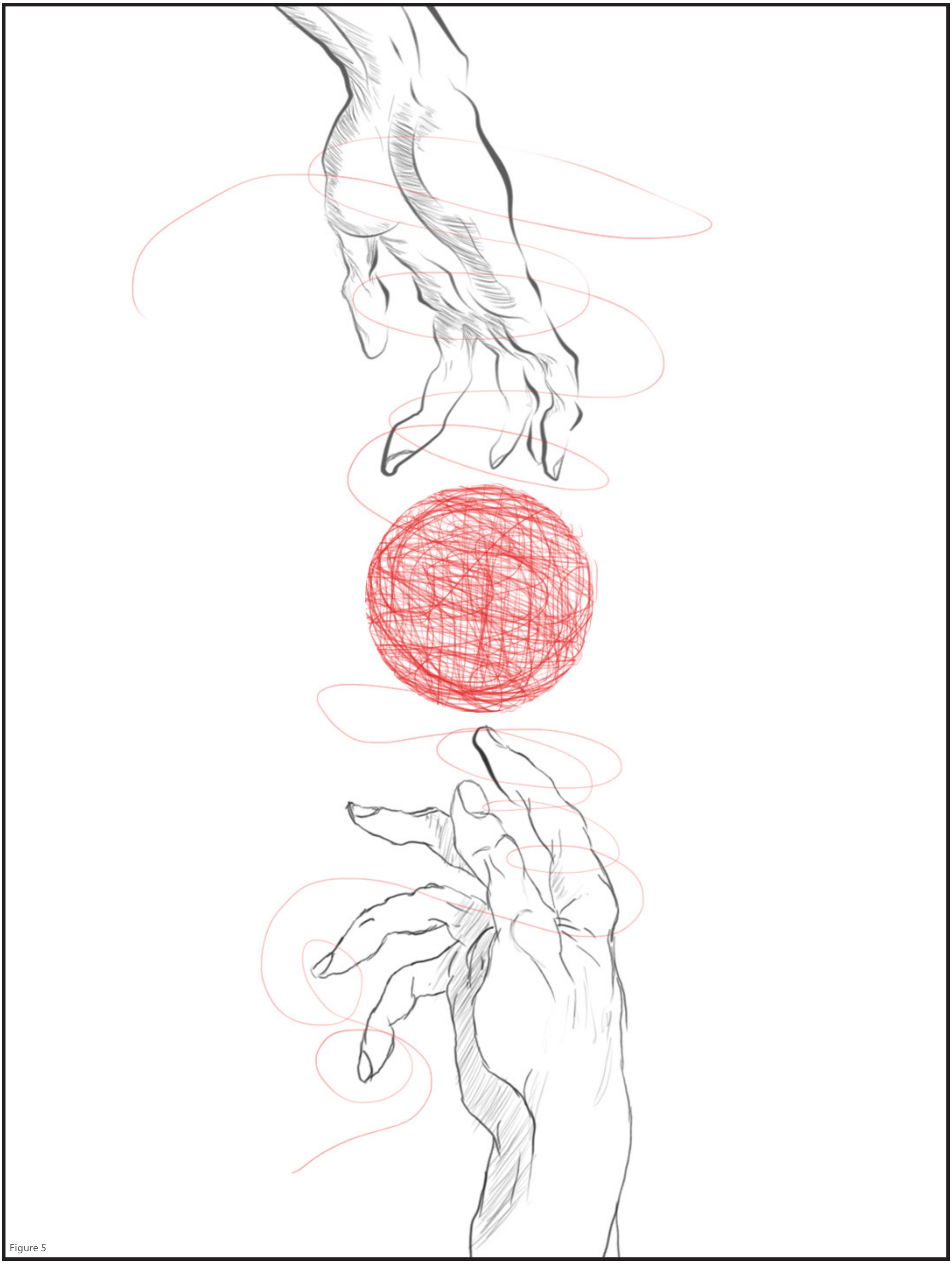


Figure 5

3. Master builder and his tools

Over a century ago, French artist Jean-Marc Côté drew a series of postcards depicting what the world might look like in the year 2000. These cards created between 1899 and 1910 predicted most of the technological development in current times. Among those postcards, one of them depicts an architect as a master builder. The illustration is quite simple where you can see an architect sitting in a box and controlling different tools to compose a built environment, though a simple idea its impact on current times is quite phenomenal as we are thriving towards the realization of this concept. If we can find a way to give back control of the fabrication process into the hands of the designer, the resulting built environment could be spatially extravagant.

Integration of robotics in architecture design and construction has paved a way towards realizing this idea of “architect as a master builder”. But even though this technology is available there’s still a disconnect between the designer and fabrication process, and this vision is not completely realized. This research speculates that humans embedded with spatial intuition have the capacity to engage in architectural fabrication via computational support. To achieve this ideology four primary architectural and technical aspects will be addressed to develop this idea each entailing their own sub-development.

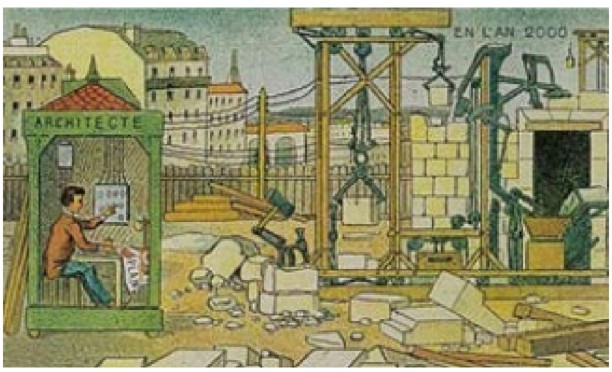


Figure 6, Architect as a masterbuilder, illustration by jean - Marc Cote

Actor – Rational and objective criteria are the elements which drive a clear and logical development in work of architecture. When we acknowledge how significant our personal feelings are in certain work, we let unconsidered and subjective ideas to intervene in the objective course of the design process (P. Zumthor, 1998).
Rational and objective criteria are the elements which drive a clear and logical development in the work of architecture. When we acknowledge how significant our personal feelings are in certain work, we let unconsidered and subjective ideas to intervene in the objective course of the design process the role of the actor is to interact, intervene and guide the fabrication process to achieve elemental forms.

Fabrication process - Desire to automate the design-to-fabrication processes has been marked with the ubiquitous presence of robots in architecture laboratories, desire to fabricate Large quantities of discrete components and automated construction has resulted in a surge of plugins for CAD software that are starting to encapsulate the required expertise. Something that is not traditional or common to robotic automation tools is this recent development (N.Vazquez, W.Jabi, 2015). Due to this reason’s robotics weaving might prove as an effective process in developing adaptive fabrication process. With primary inputs form the actor, robotics weaving can act as a medium between the sketch phase and fabrication phase to develop elements in a real-time physical environment.

Tactile material – To manifest human gestures and movements to a concretized form selected material has to tactile enough to accommodate changes in its shapes. Materials such as a woolen thread, ropes, fiber rush would be experimented to identify possibilities and limitations to develop a fabrication process easy enough to execute using robotic weaving

Tangible feedback and sensor interfaces – A sensor interfaces and feedback system will tie all the above mentions aspects together to create a data library, which works with the actors, suggests possible solutions and records physical feedback to develop different elements. This data library will also inform the user about the different loops and paths available for the robotics weaving process.

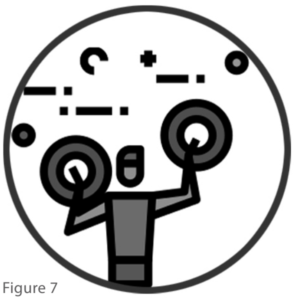


Figure 7

Actor

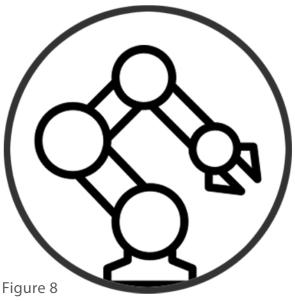


Figure 8

Process

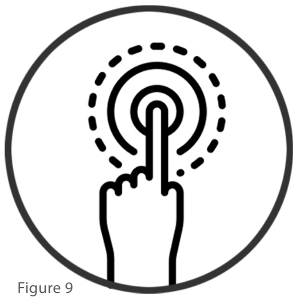


Figure 9

Feedback

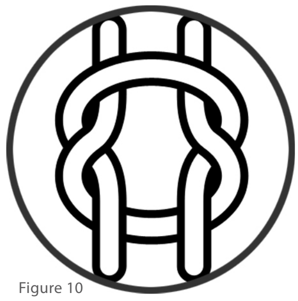


Figure 10

Material

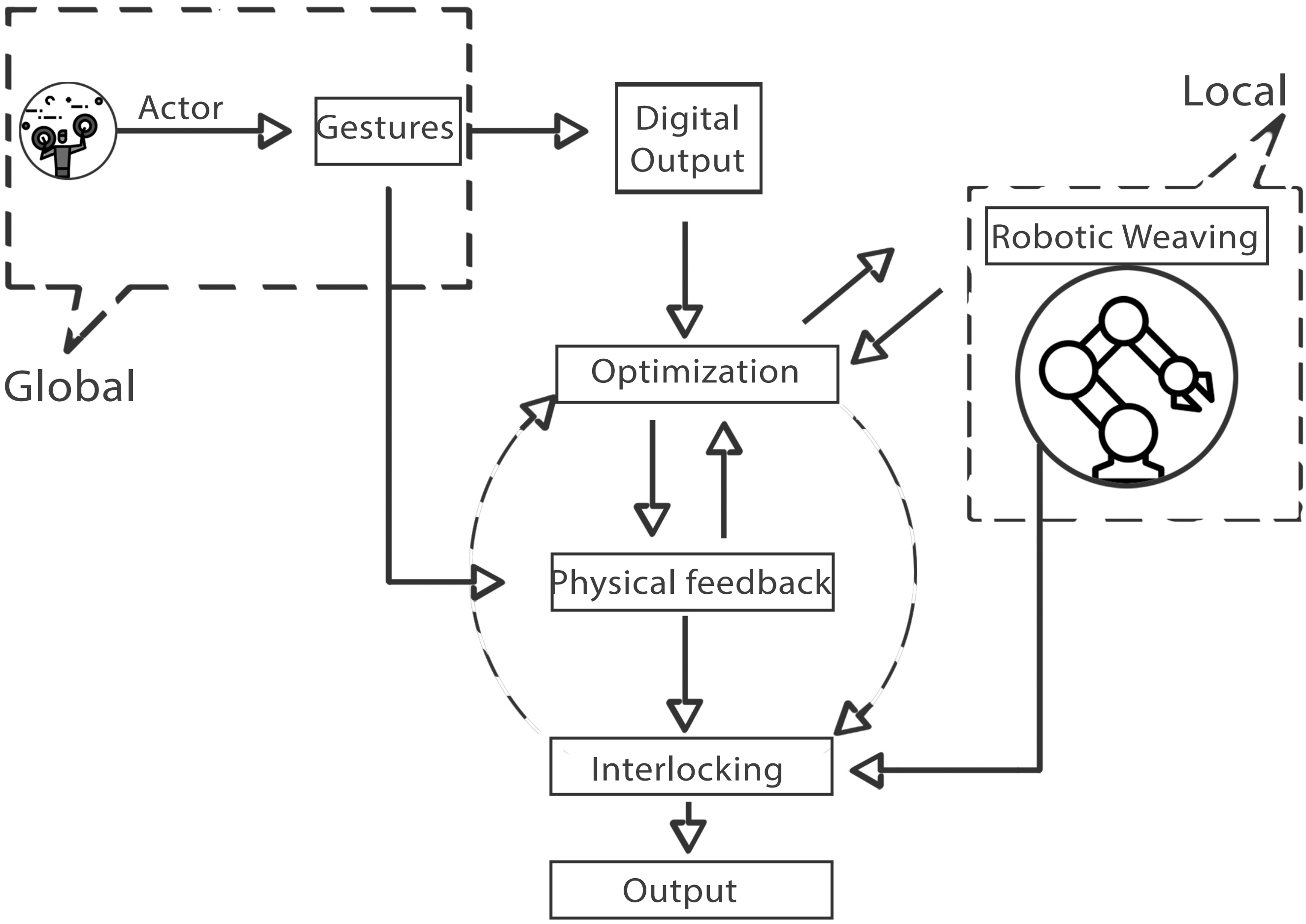


Figure 10, Illustrations from Flaticon.com

4. Deus Ex Machina

The quality of a design result, in the real world, is determined by compliance constraints and the degree to which they have been achieved. In design development and digital fabrication, these robotic tools have become more coherent as the technology evolves at a tremendous speed intertwining experience and environment together. As the title suggests “Deus Ex Machina” which means - an unexpected power or event saving a seemingly hopeless situation, especially as a contrived plot device in a play or novel, use of robotics in architecture has brought about an unexpected change where this technology previous alien to designers has now become readily available and with its integration with existing cad software has enabled us to imagine beyond traditional fabrication process.

As one of the objectives of this thesis is to examine the possibilities of human-machine learning and robotics fabrication process, an 8-fold process which works in a loop has been developed to provide a collaborative works space for the designer and robotics to develop architectural elements in real time physical environment. But before we dive further into the fabrication process it is important to understand how these loops work in a digital environment and how a user can intervene into those loops to achieve harmony. Two examples of such collaborative work environment exist in fabric weaving and music production industry.

Figure 11, Deus Ex Machina, painting by Giuseppe Tersigni

4.1 Fabric weaving

Fabric weaving using a loom is a traditional method of making clothes and tapestry, a loom is basically a machine or frame of wood or other material, in which weaver forms cloth out of thread, it is designed to repeat certain movements like lifting strands of thread based on the inputs given by the weavers. Weaver decides what pattern to go with and based on the pattern the initial setup of the loom is decided. Figure xx and Figure yy show two different elements used in looming – warp and weft. The fabric is woven using a thread running vertically called warp and thread running horizontally called weft, this allows the fabric to be rigid in one direction and flexible in other. Once the initial set up is complete both the weaver and loom work in a collaborative process to complete the weaving of the fabric with the desired pattern.

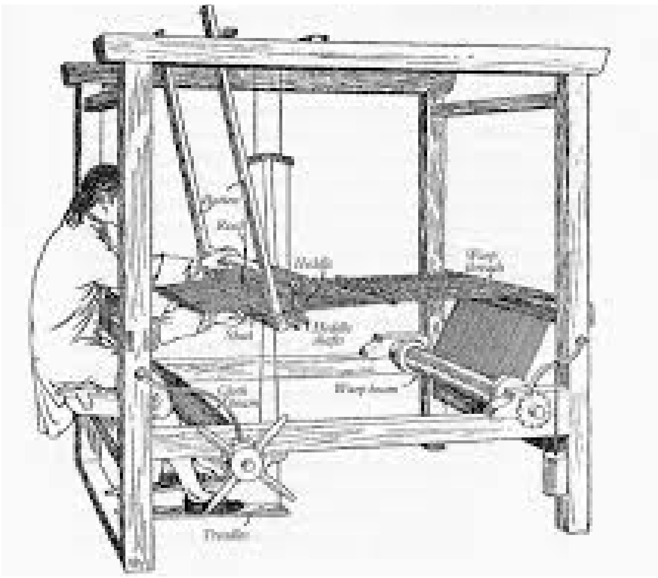


Figure 12, Traditional loom, Source - Google

4.2 One – Man orchestra

One - man orchestra is a term in music which signifies that different instruments like guitar, drums, piano are been played by a single person to compose a melody. The way they compose these songs is by putting different beats on a loop using a synthesizer, the artist starts by using an instrument, composes a beat, which is then recorded digitally to be played in a loop in the background. Once satisfied the musicians moves to different instruments follows the same process of recording and looping to compose a melody made of different instruments played on a loop.

Figure 13, Automatica - robots vs. music - Nigel Stanford

5. Understanding Robotic weaving

For fabrication and assembly architects have already adopted industrial robots over the last decade, these new tools offer flexibility to manipulate a variety of deformative, additive fabrication processes (McGee, W., M.P. de Leon, and A. Willette, 2014). These robots can fabricate complex three-dimensional geometries which combine the potential of parametric and generative design and modeling which is currently beyond the capabilities of conventional fabrication techniques (S. Sharif, T. Russel Gentry, L. sweet, 2016). The robots used for this research are Universal Robots (URs), Specifically UR5, this is small industry robots which can be operated easily and has several special features that make them differ from the other industrial robots Operational space of these robots is 850mm and has nine kinematic solutions meaning they can reach any point in most of it working space, with online direct upload and safety features these robots are compatible to work among humans.

These versatile industrial robots which are programmed to achieve the assigned task are ultimately defined by the controlling software. Usually manufactures define a written programming language for the robot which is used for executing an assigned task. The program includes a set operation that the robot executes one by one sequentially. In industry, manufacturers supplied software are used to program these robots. With the recent introduction of robotics in architecture, a more familiar design environment is now being developed to control these robots where many successful programming tools for robotics are being developed to address the need of the architectural field (K. Elashry, R. Glynn, 2014). Apart from the unidirectional axis of the robotic arm and the software another important element which detects the working of the robotic arm is End Effector.

What is an end – effector

An end effector is a tool which interacts with the physical object. Its objective is to act as machinal fingers to complete an assigned task. Different end- effectors can be developed depending on the operations to be performed. A custom end effector will be developed to achieve robotics weaving in this research thesis.

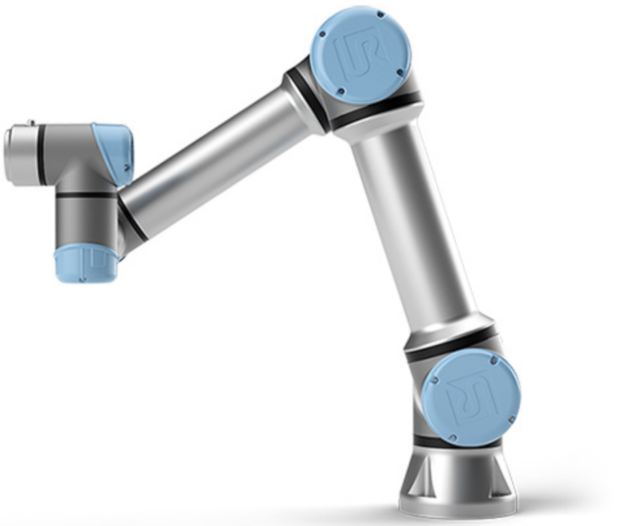


Figure 14, UR5 robotic arm, Universal Robots website

Figure 15, Elytra filament pavilion by Universsity ofStuttgart

5.1 Experiment

To understand the working of the robotic arm and its limitations. Different experiments were carried out, which involved developing custom end effector and waypoints. A simple exercise of making a line sketch with the arm was proposed to understand the working parameters of the robotic arm.

An end effector was developed which can hold 4 markers of different colors. These markers would then be used to make a line sketch, line sketch was developed on rhino as a polyline model which was then exported to RoboDK (Standalone software for programming of the robotic arm) where line geometry was then translated into waypoints for the robot.

5.2 Findings

It was observed that to use the robotic arm as fabrication tools for weaving several factors and parameters play an important role. The robotic arm used for this experiment has a working reach of 80cm and is fixed to a base which limiting its IK movements to half. To use different colors for making the sketch, a pre-defined set of lines had to be created in order to program the robot to switch colors. This experiment gave a technical insight into the working of the robotic arm and helped develop a methodology of the research framework. Also based on the results of this experiment conceptual ideas for the end effector (to be used of weaving) was developed which is described in the next chapter.

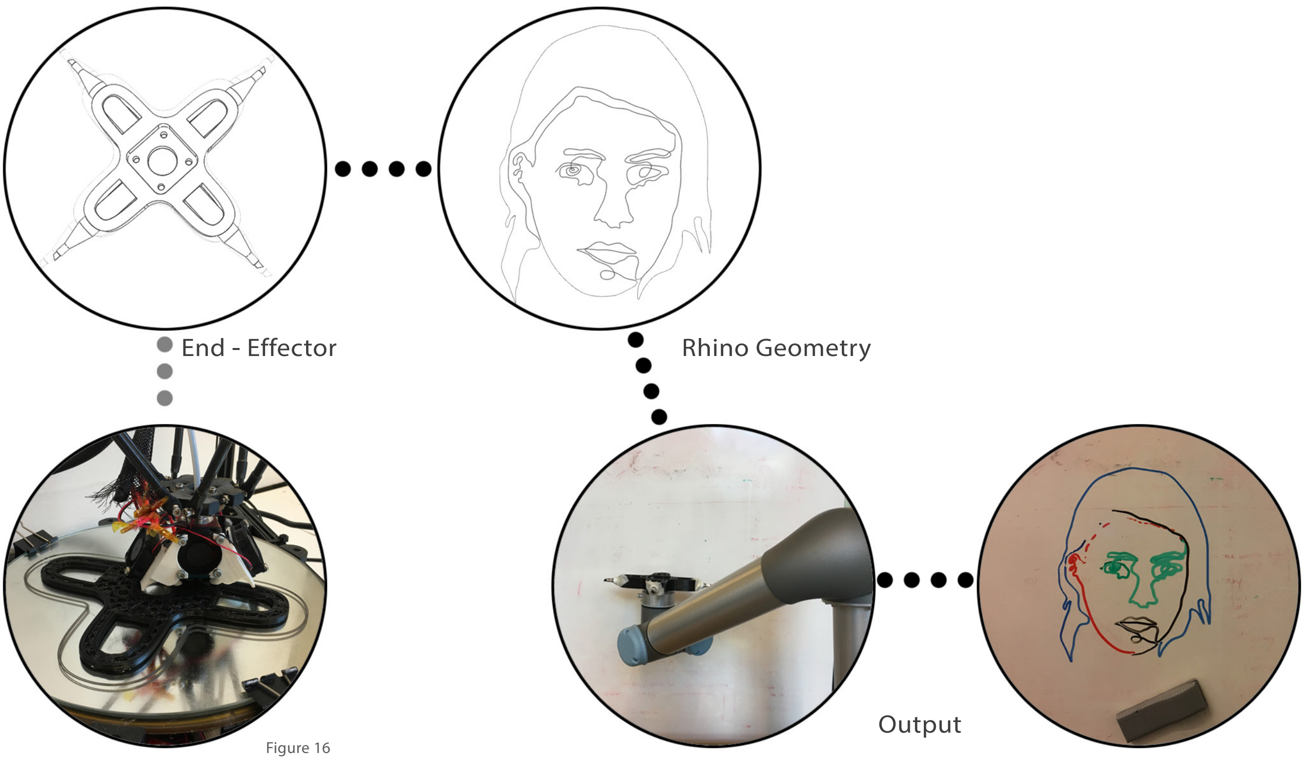


Figure 16

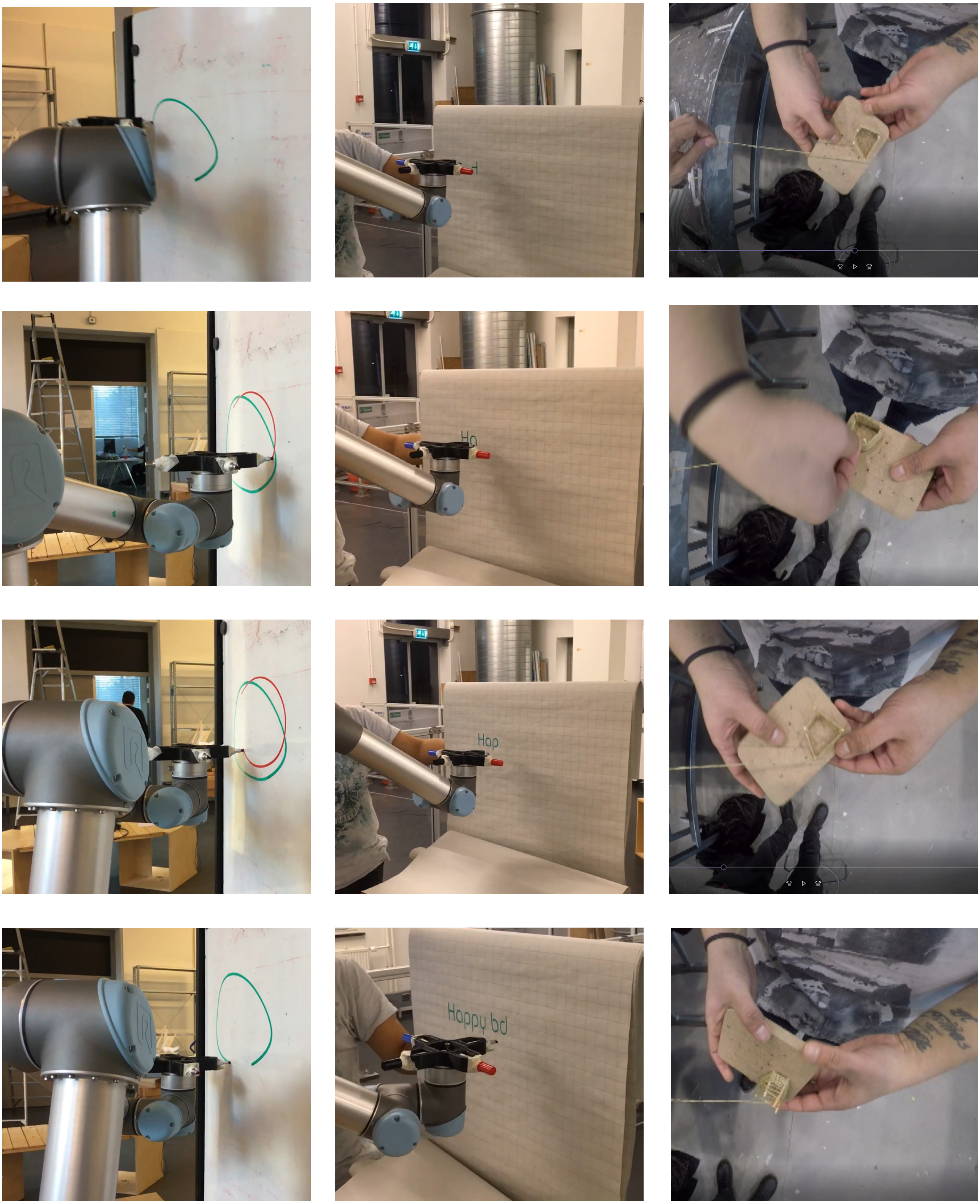


Figure 17, experimets and tests

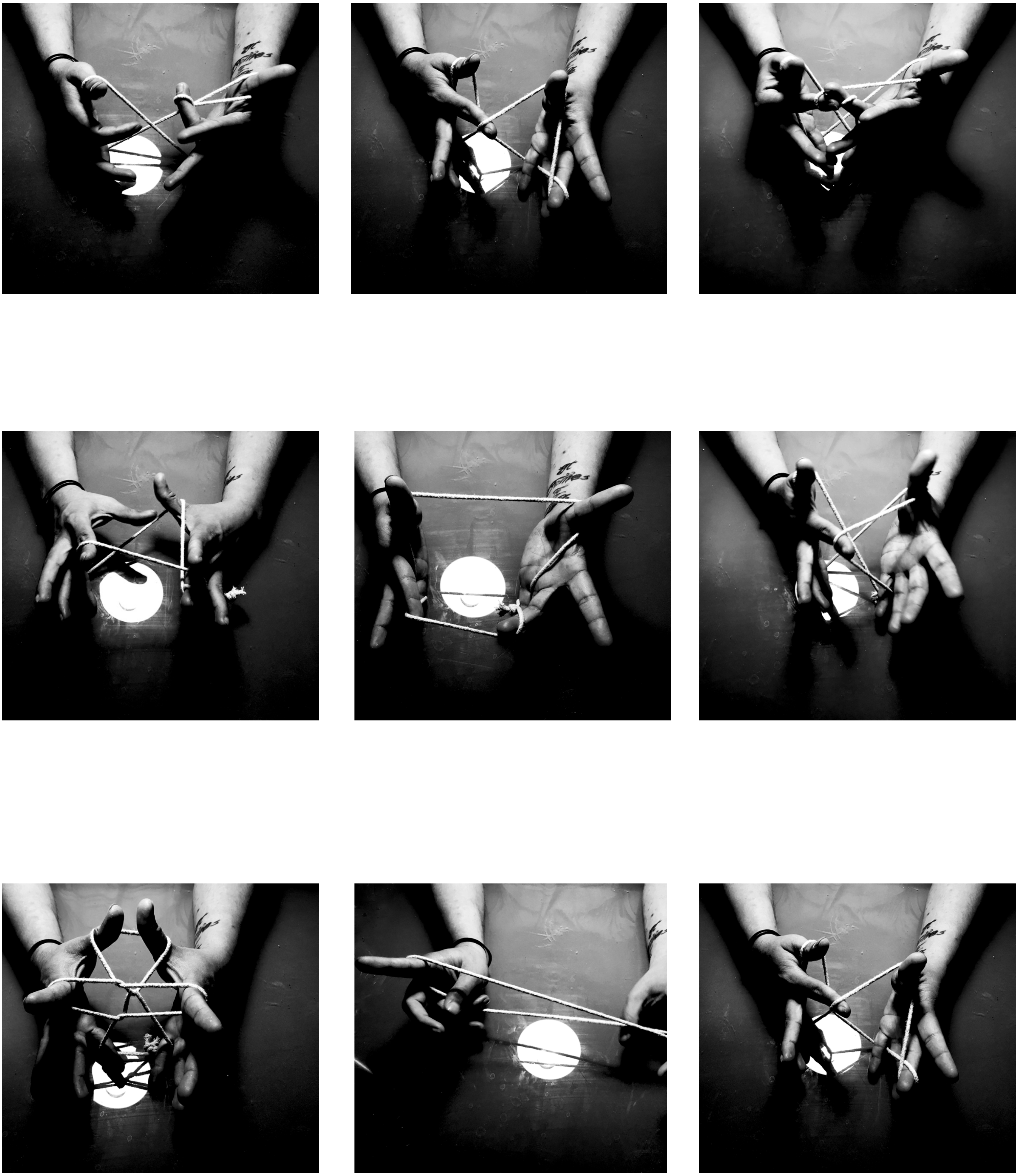


Figure 18, experimets and tests

5.3 Physical Models

To dive further into the idea of weaving using the robotic arm, several scaled models were made (without using the robotic arm). Thought behind this experiment was to understand how weaving, hand gestures, and movements are used to achieve the indented design pattern. Using basic material like a wooden stick, a rope and an MDF base this scaled model gave insight on different tasks performed by the hands to weave, these observations, combined with findings from the previous experiment were then applied in developing a concept for a custom end – effector for the desired fabrication process

Figure 19

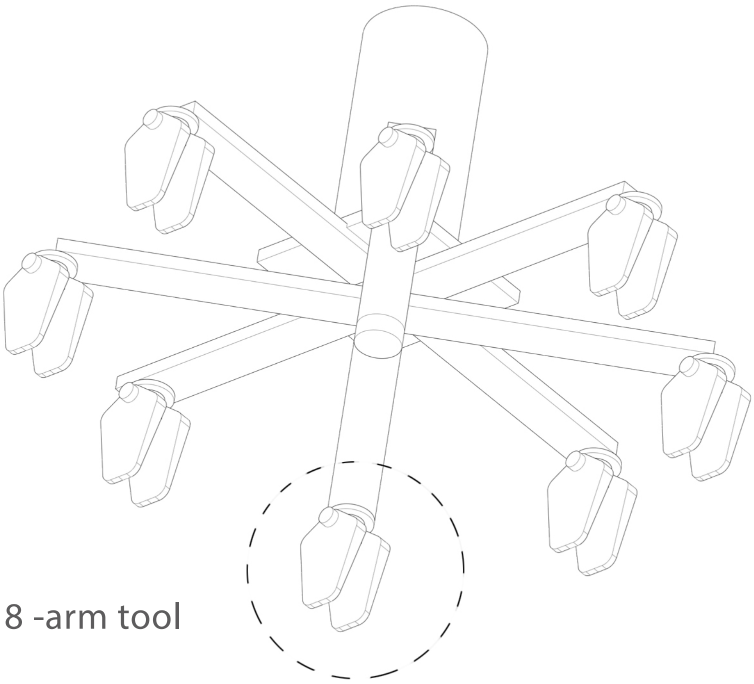
Figure 20

Figure 21

Figure 22


Figure 23

5.4 Developing custom End - Effector



Different designs and concepts were developed for the end – effector which is to be used for this fabrication process. One of them involved deconstructing the process of loom weaving, this end effector was developed in a way that it creates slots to hold framing elements at different heights and angels in working space. This tool was developed in accordance with the fact that it must be tactile to adapt to changes performed by the designers. Following illustrations shows conceptual ideas of an end effector. Over a period of this design, the concept was abandoned towards a simpler tool which can be operated easily.

Different versions of an end – effectors were developed depending on the fabrication requirement, simplicity and user adaptability. Each of this end – effectors are assigned with a specific task which involves weaving, Drilling at assigned points and giving feedback for interaction and design evolution. Each of these end effectors is further explained in the report depending on the scale they are used for.

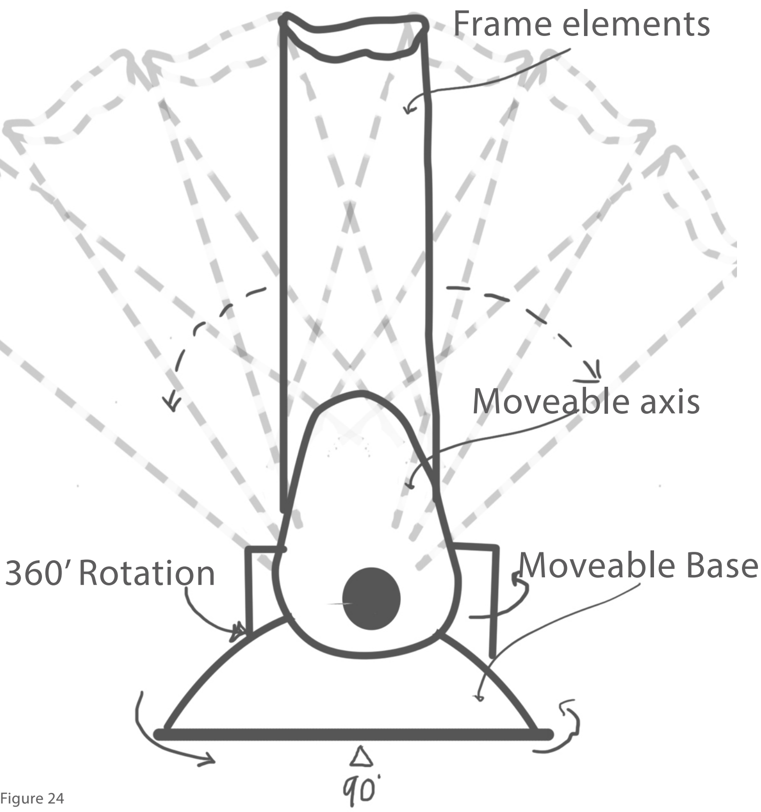


Figure 24

5.5 Material

The material used to test this tool is fiber rush, this material resembles a natural twisted cattail rush which is made of durable and twisted paper. This material provides tactility and when combined with a strong adhesive can be used to weave different elements which can stand structural loads. The adhesive used for this process is bio epoxy resin in which the paper rope is soaked before starting with the weaving process.

Figure 25

6. Process and Tools

Initial experiments and research gave insights on fabrication possibilities using an industrial robot, based on this study custom process and tools were developed which will provide a controlled environment to establish an interactive connection between the robot and user. The research scope of the thesis deals in detailed development of this tool on a smaller scale where the architect can use this process to developed local elements like a chair or table and a conceptualized construction process is proposed where this same process and be applied on built space thus proving the proof of concept for this method on a global scale.

6.1 Introduction – Local scale

To perceive an object as a whole it is very important to understand the individual elements which make the object, when we detach our self from this object and deconstruct it to its very basic form is only when we can start rebuilding it from scratch using a completely new process altogether.

As established before, the research and design process for this thesis was divided into two parts - Local and Global. At a local scale, different day to day objects like chair or table were considered, Reason behind choosing these objects were established on the familiarity of architectural language which helped in simplifying the process of developing this interactive tool. Several different parameters and user inputs act together in a sequence to achieve the desired intent. This method of design and fabrication was developed on a set of rules and limitation which is always the case when it comes to developing any CAD-based design program.

This interactive fabrication process at a local scale is achieved based on user gestures, typology, material, and assembly. These parameters work together to form different object elements which can be interlocked into an overall system. A conceptualized program, script and end - effector were developed which acts as a medium between architecture and instrument.

6.2 End effector – Local scale

Fabrication adopted for this method required an end – effector which acts a needle weaving the thread around a set of supports, based on this concept end-effector is composed of 3 parts – Spool, adhesive container, and nozzle. Following illustration describes this end – effector in detail.

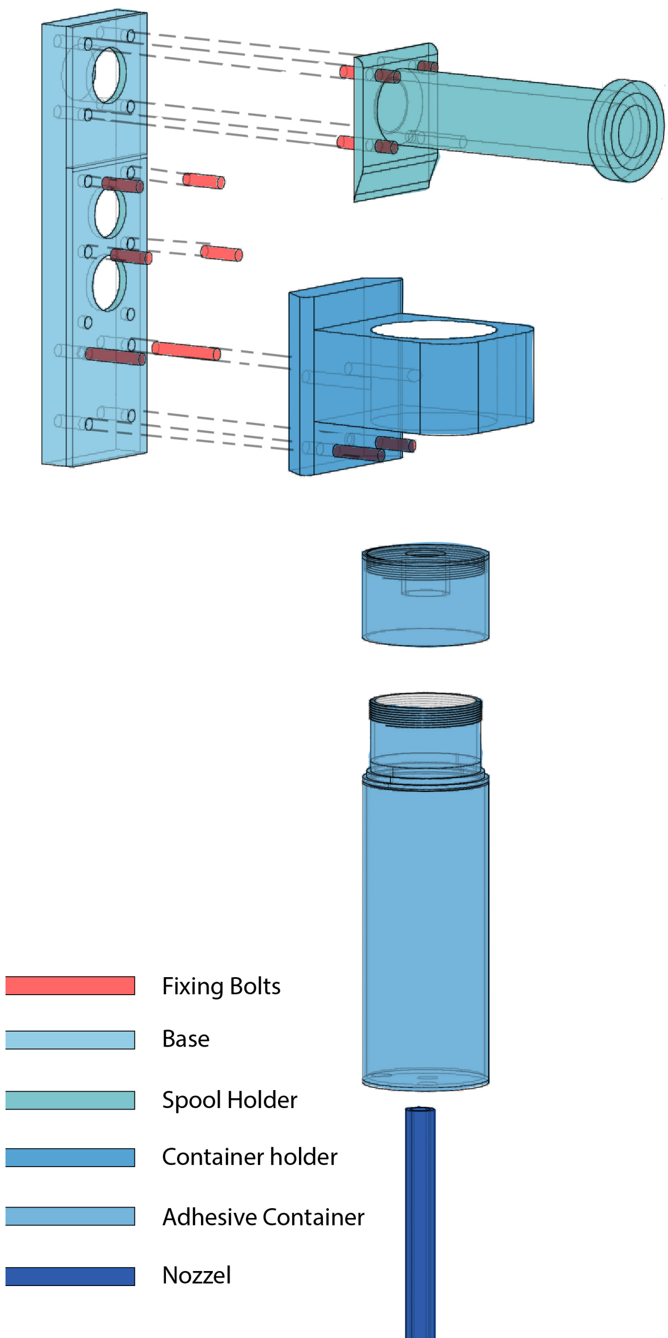


Figure 26

7. Rules and parameters – Local Scale

At the local scale, a set of rules were developed which not only assist the architect with the design process but also simplify the whole process of tool development. These rules were developed based on operating range, material, and user inputs. To simplify the detailed working of this tool, the development process was divided into 5 different Phases. Following are the set of general rules developed Phase 1.Different hand gestures and hand signs work together to develop forms and shapes.

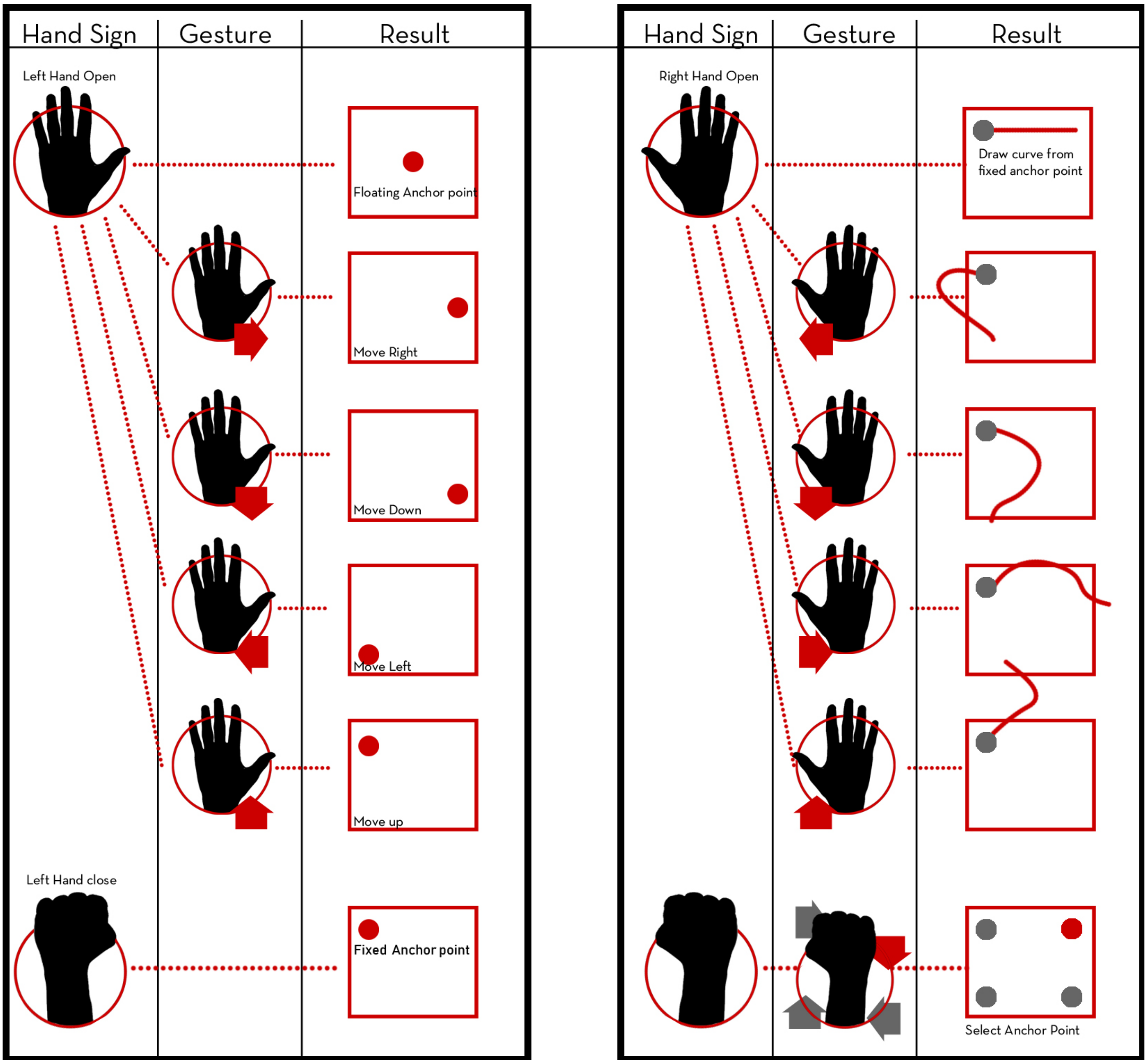


Figure 27, Gestures and instructions

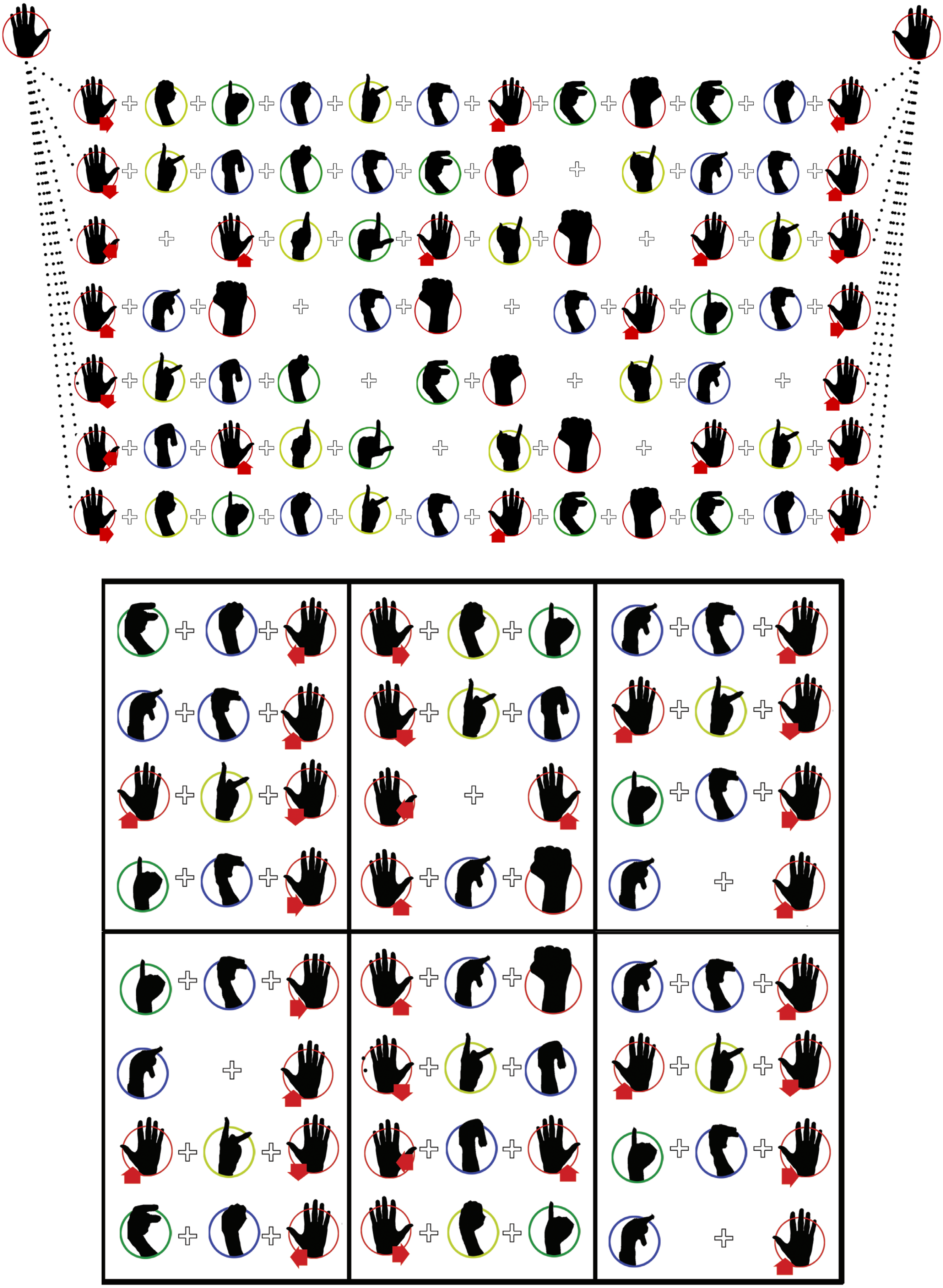


Figure 28, Gestures and instructions

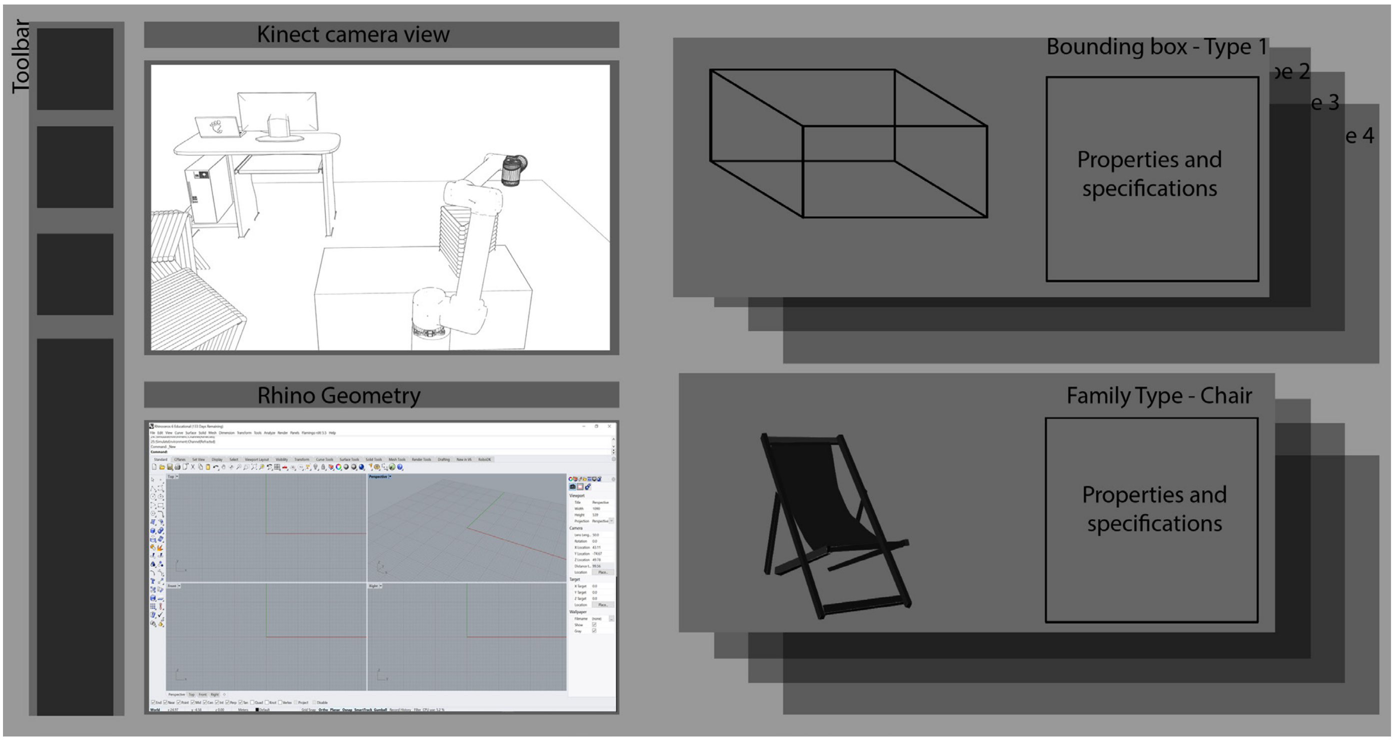


Figure 29, Gestures and instructions

Phase 1

- A bounding box of defined size should be selected based on design intent.
- A Total of three curves can be made at the initial form development.

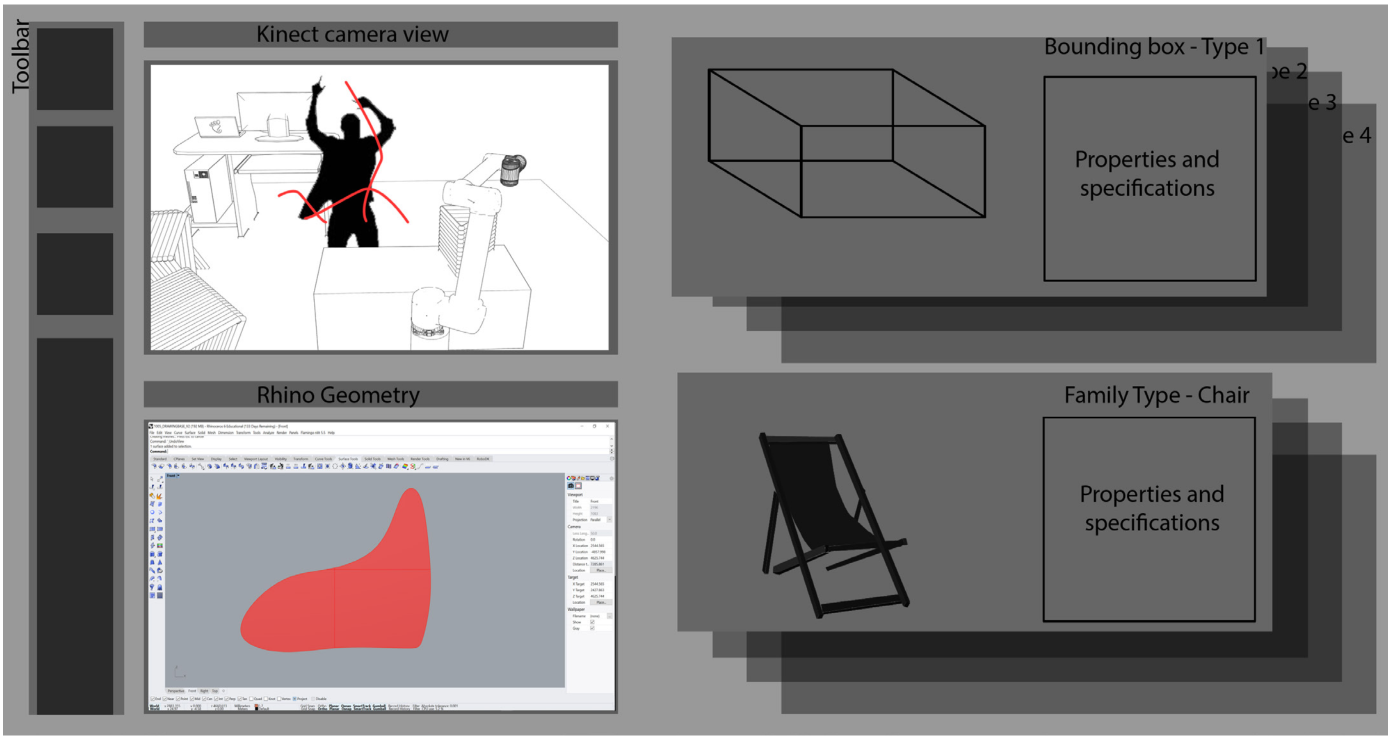


Figure 30, Gestures and instructions

Phase 2

After completion of phase one, the program suggests different typologies of form which can be achieved from the curves received as user input. Following are the set of rules at Phase 2

- Change in bounding box size.
- Change in a set of curves.

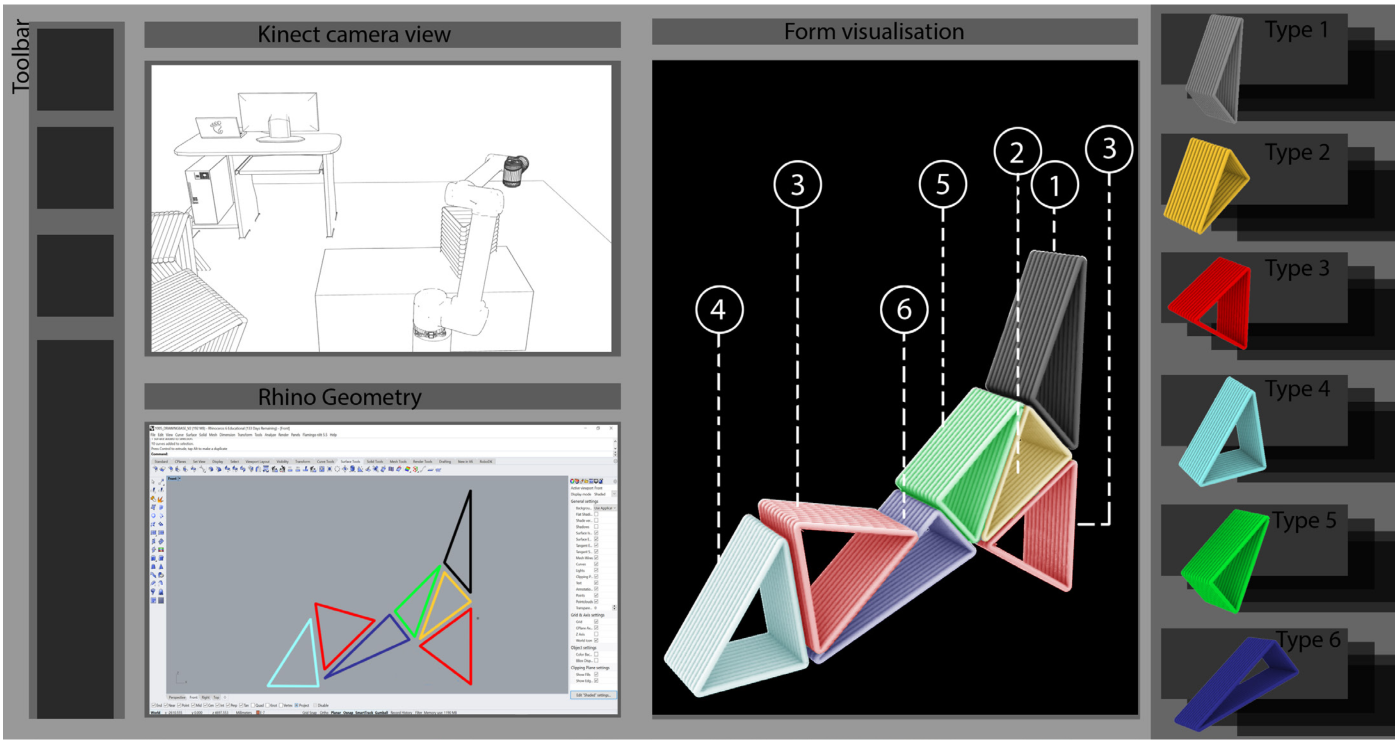


Figure 31, Gestures and instructions

Phase 3

Phase 3 is initiated when the architect approves of the initial form, at phase 3 the conceptualized form is converted into a family of triangles based on structural parameters. Following are the set of rules at Phase 3

- Bounding box size cannot be changed at this phase.
- Curve set cannot be changed at this phase.
- Family of the suggested triangle is tangible and can be changed.
- The density of these elements is also adaptable.

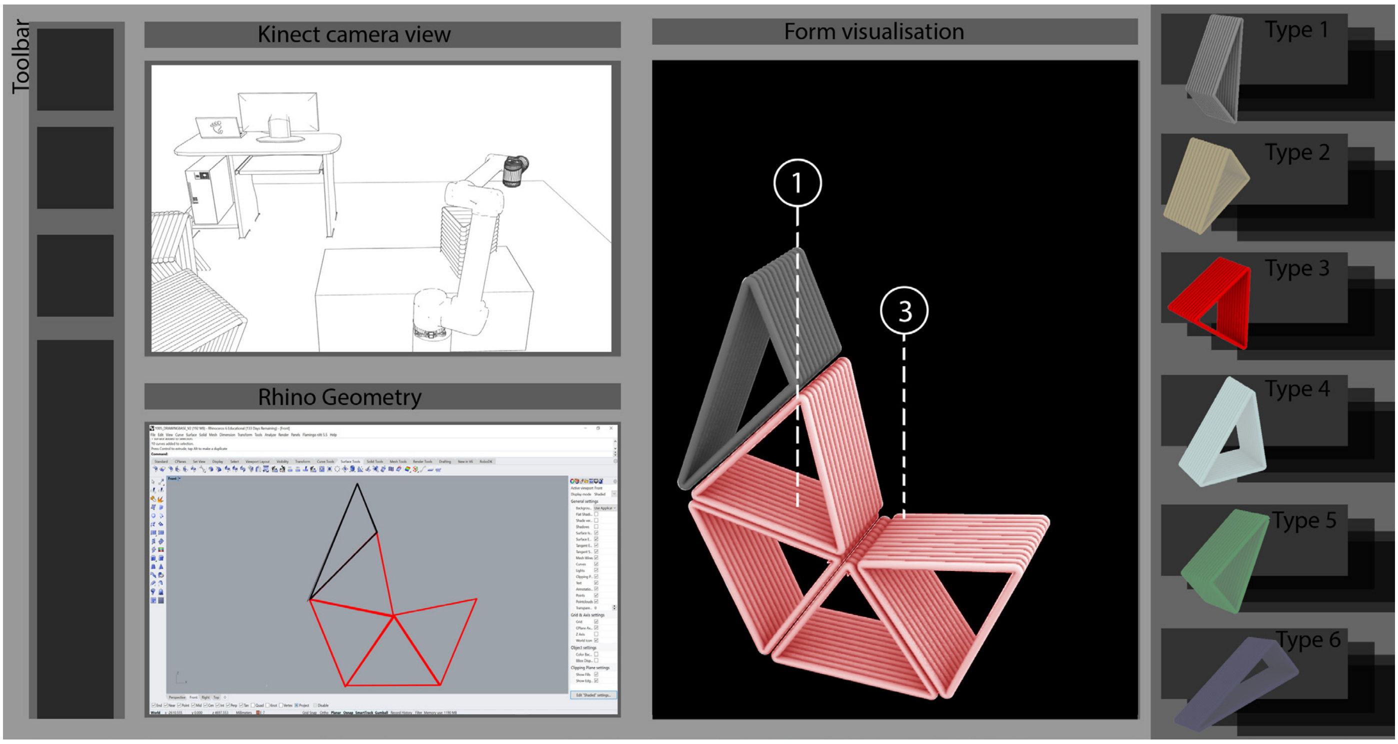


Figure 32, Gestures and instructions

Phase 4

At this phase the architect can decide to alter the family of this suggested triangle and can adapt the shape based on his intuition, role of the program in this phase is to analyze the changes made by the architect and suggest if the new family of triangle is suitable for the shape or not based on parameters of structure and first three phases.

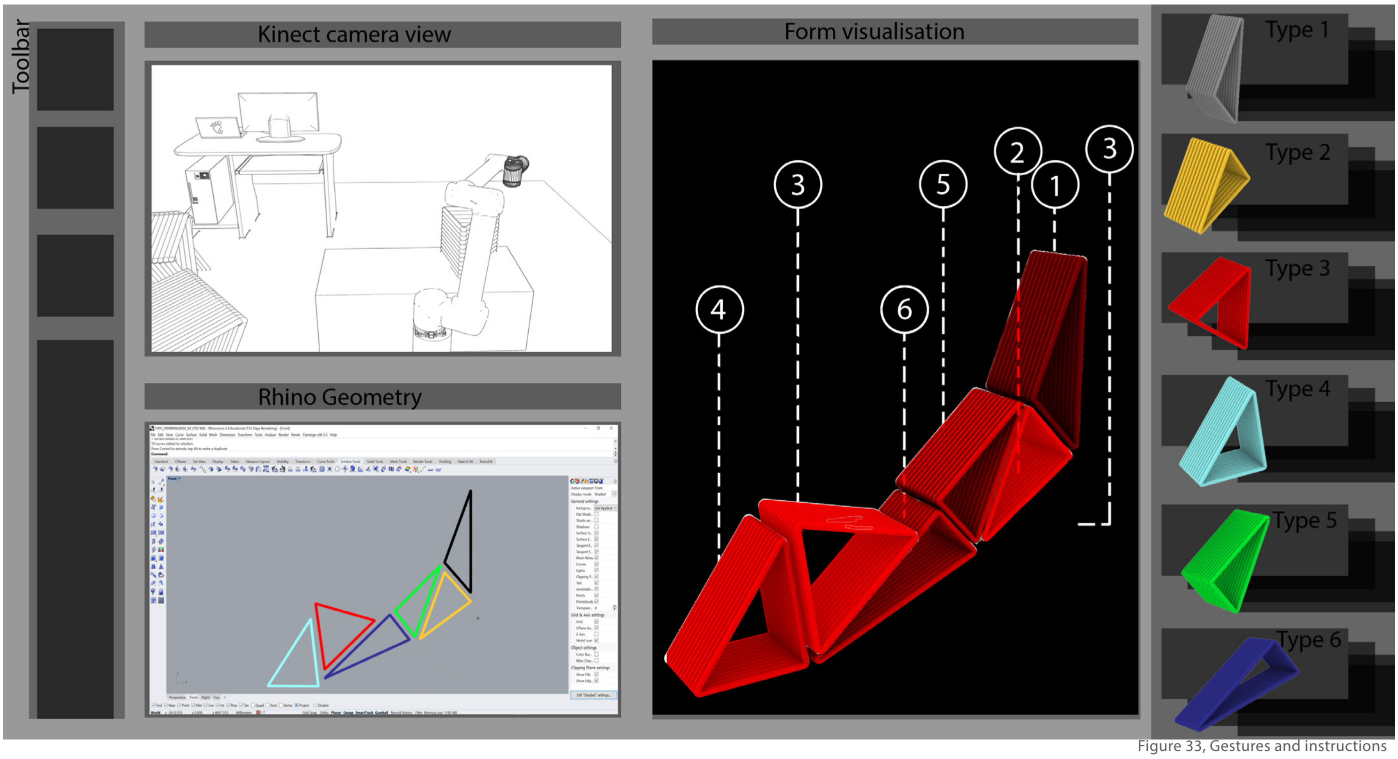


Figure 33, Gestures and instructions

Phase 5

Assembly of the weaved family of triangles is initiated at phase 5. These different family of triangles are interlocked into an overall system. At this point, a new family of triangles can be added into the overall system, upon performing this action the program analyses if the changed geometry fits the assigned parameters and responds accordingly. Following are the set of rules in phase 5

- Inputs from the first Four phases are absolute and cannot be changed.
- Based on parameters architect will have to adopt the altered family of triangles.
- A new family of triangles can be added.

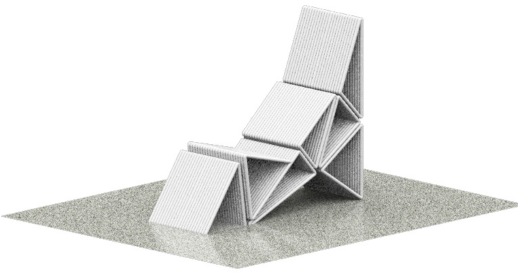
These sets of rules and parameter act sequentially to develop a controlled environment where both the user and the robot learn from each other. This shared knowledge results in a design and fabrication process where the architect is working collaboratively with the tool to develop a coherent design.

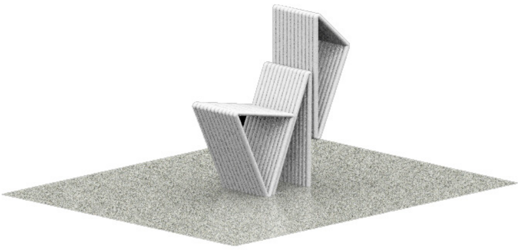

Figure 34, test models

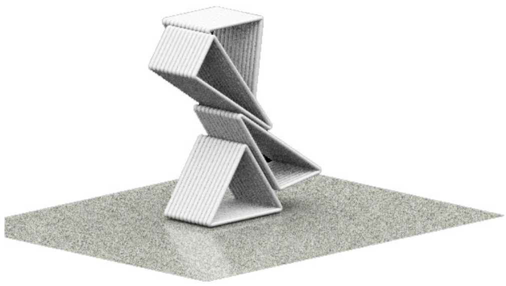
Figure 25

8. Variations and end results

Digital tool combined with developed end effector yielded various design iteration and elemental families, which can be interlocked into an overall system. This variations and end results are proof of concept for this developed methodology and answer our initial research objective which was to develop a tool and process which integrates robotic weaving and human-machine learning and use this developed methodology to study its impact on the design and construction language. This method introduces a new approach towards traditional architectural elements embedding the architect within the fabrication process, resulting in a collaborative environment.







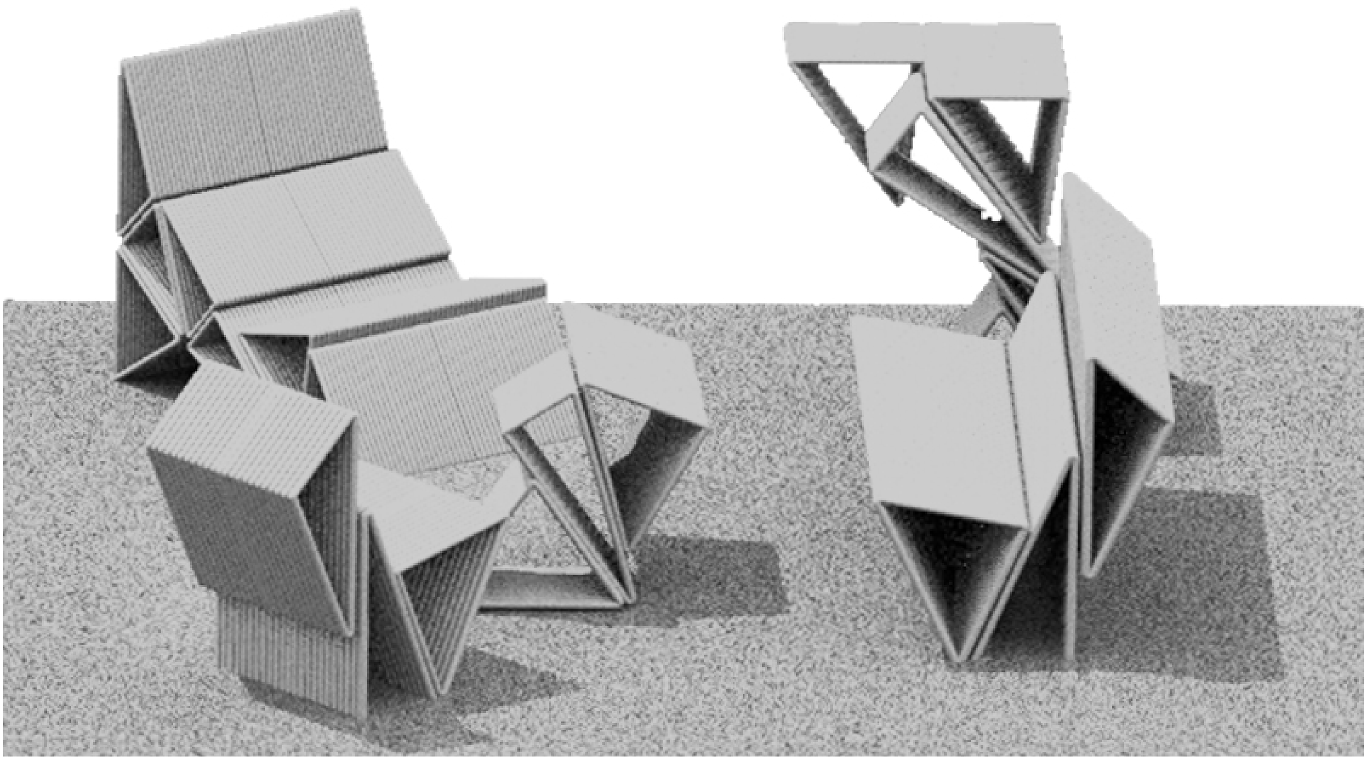


Figure 35, variations

Figure 36, variations

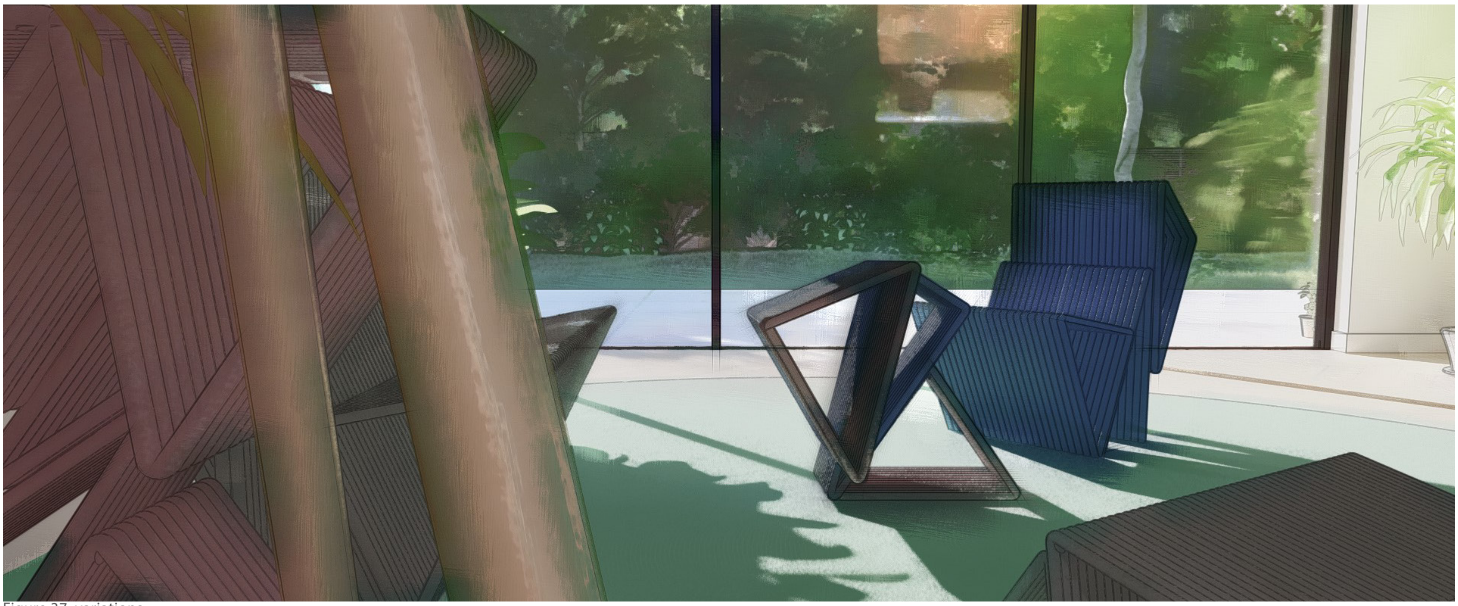


Figure 37, variations


Figure 38 variations


Figure 39, variations

9. Introdution - Global scale

Program and methodology developed for local scale laid foundation for the conceptual development of adopting this method at a global architectural scale which these elements can be interlocked together to form a built space. To apply his design process at an architectural scale a traditional design program and case study was selected, the only difference in this design approach was speculating the idea of using interactive robotic weave as a construction and fabrication process.

With the experience and results from the variations developed at the local scale, design language for this case study was developed accordingly and is described in 5 key stages – Case study, Architectural concept, Methodology, construction design, and Technical drawings.

9.1 Design Idea

To represent and speculate possibilities of using this newly developed tool it was very important to develop a design language considering the practicality of a new construction method where robotic weaving can be used to introduce an idea of a built space which will represent different characteristics of familiar architectural elements but are completely alien to visual perception. These elements which can then be introduced in this intricate ergology of systems where rather than standing out it blends into its surroundings leaving only traces and familiarity of what we call a built space.

Figure 40, concept visualisations

9.2 Case study

As a case study an abandoned rock mining site named Jaspe Quarry located Serra da arrabida, Portugal was selected, reason behind selecting this quarry is because of its massive cliffs dropping dramatically into the Atlantic Ocean, together with its remarkable place within a powerful natural scenery where the landscape is carved out of remains of an old quarry. Located on a prominent landscape, this site can be interpreted as a poetic expression of the developed fabrication process where instead of a robotic arm, nature has collaborated with man to weave a place of solitude and memory creating a tranquil atmosphere for remembrance and introspection; laying a conceptual foundation of designing a built space which can radiate a intimate journey through time and silence, fragments and space which would offer an individual a unique experience within the immensity of the place. The Jaspe Quarry was closed in 1976 when the Arrábida Natural Park was created. The abandoned quarries display the natural beauty of the 'Arrábida Brecha' which is an ornamental stone unique to this quarry which is used in several monuments within this region (also known as "Arrábida Marble").

Figure 42, site picture,ARKxSITE

Site Description

Latitude: 38°27'28.38"N

Longitude: 9°00'37.63"W

Altitude:235 m

Winds: Predominant winds are from the north.

Climate: Warm and temperate climate.

The annual average temperature is 16.6 °C.

Relative Humidity: The annual average relative humidity is around 68%.

Rainfall: Total average annual precipitation is 679 mm. The driest month is July, with an average of 3 mm of precipitation, and the highest rainfall is in November, with an average of 103 mm. The hottest month is August with an average temperature of 26°C and the coldest month is January with an average temperature of 13°C.

Figure 41, site picture,ARKxSITE

Figure 43, site picture,ARKxSITE

9.2 Architectural concept

Initial experiments and research gave insights on It was essential that design proposal emphasizes, respects and celebrates the site when it comes to generating a vision for an intervention located within such a spectacular place while providing individuals with a sensory experience. This experience will be a curated display of speculation in robotics and user interaction and for this purpose architectural concept developed revolves around the idea of introducing fragments of architectural elements into this perceptive environment where this elements represents a familiarity towards a traditionally built space but conceives a completely alien form when perceived visually, creating an architectural environment where one cannot differentiate between a column, wall or a beam as these elements won't have any evident visual representation, the built space should be so powerful that it detaches the individual from himself and make him question his place in the context and the built environment. To represent these ideas collectively an abstract form of Mausoleum is proposed to value and appreciate the nature of context, Following design programme details out the various spaces incorporated into this mausoleum. Design programme includes entrance, observation decks, and resting/outdoor area.

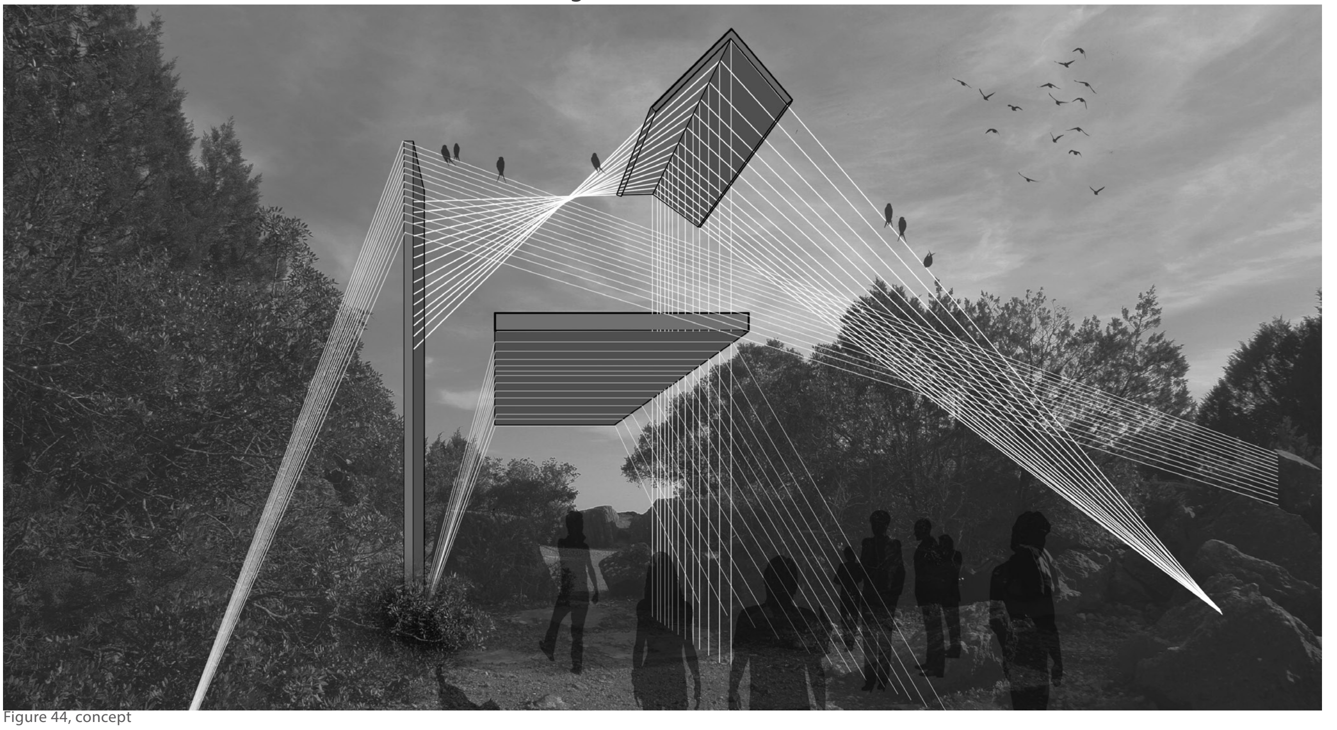


Figure 44, concept

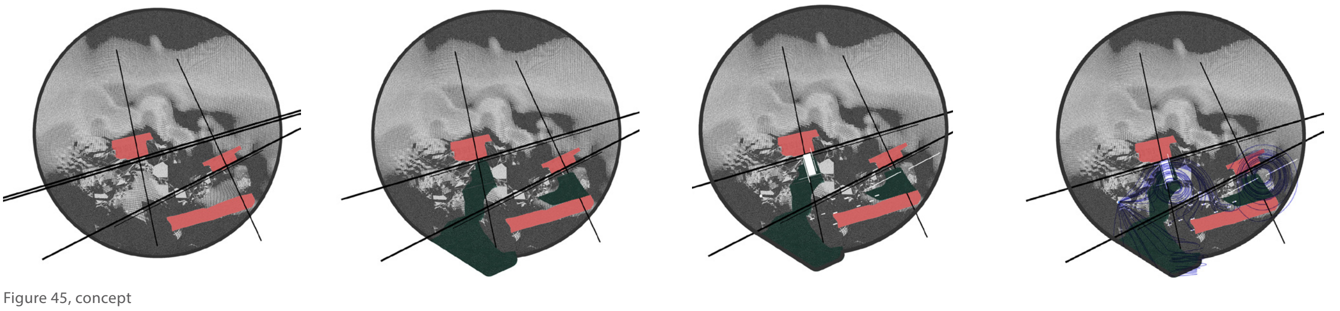


Figure 45, concept

9.3 Methodology

Applying ideas and concepts from local scale methodology, this process speculates an interactive environment at a global scale where the architect can embed himself within the site to develop design languages based on the established concept which is described in the previous chapter. Several different parameters and rules come into action when it comes to developing a digital tool which is adapted for this larger scale when it comes to the matter of architectural spaces various aspects of practicality and construction details comes into play. following illustrations speculates working of the developed digital tool at a global scale, end – effector, construction drawings and details required to execute the design on site and working details for the robotic arm. Just as local scale process developed for this design approach is developed based on architectural parameters, end effector, rules, and parameters.

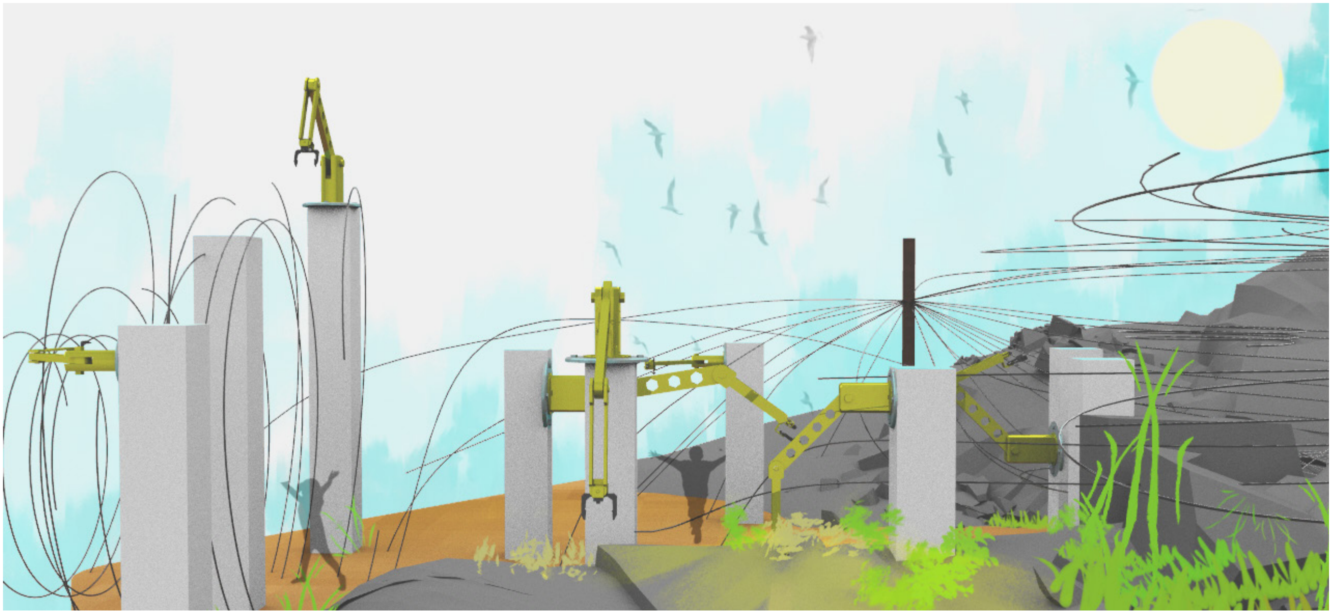


Figure 46, process visualistions

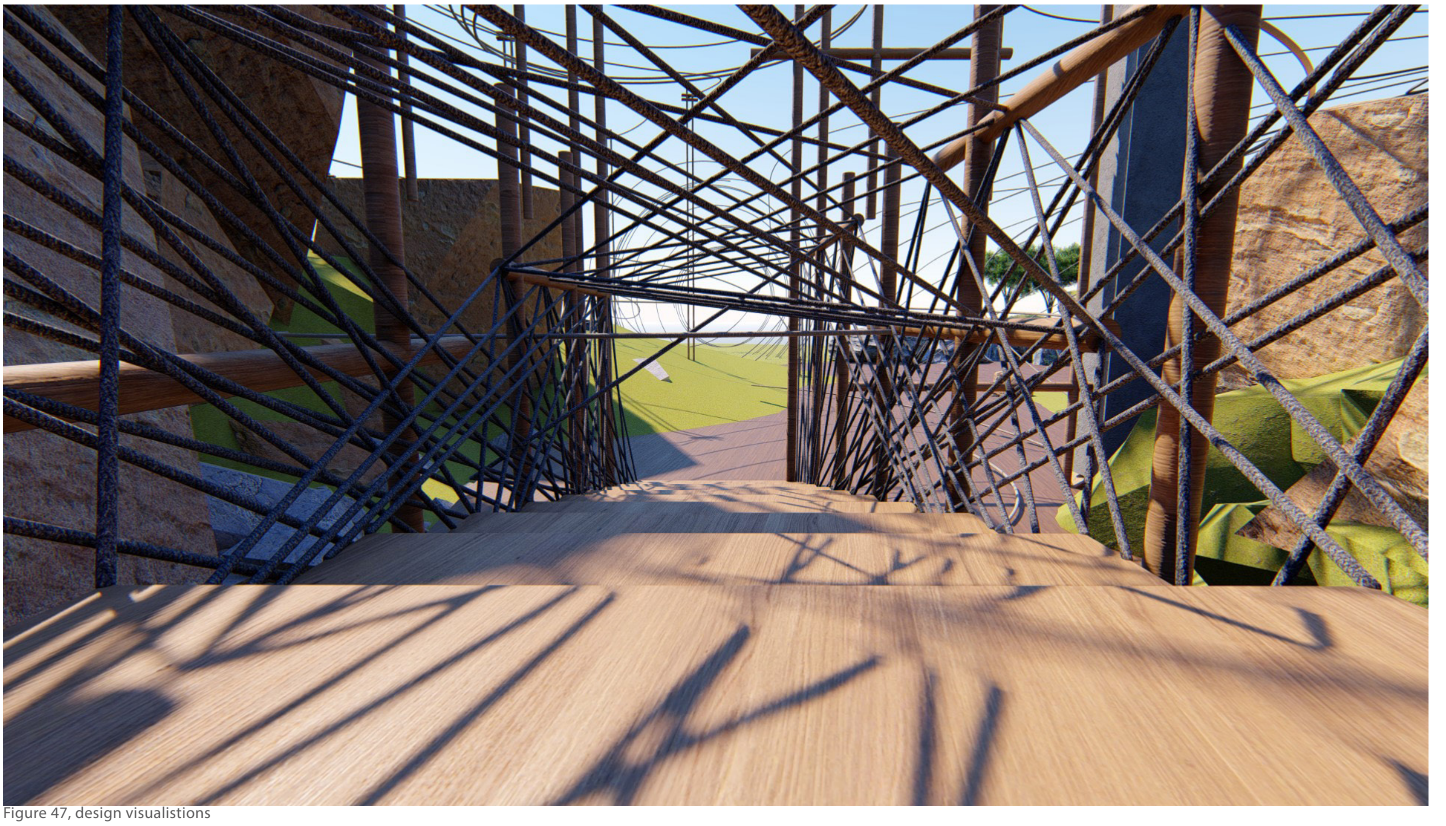


Figure 47, design visualistions


Figure 48, design visualistions

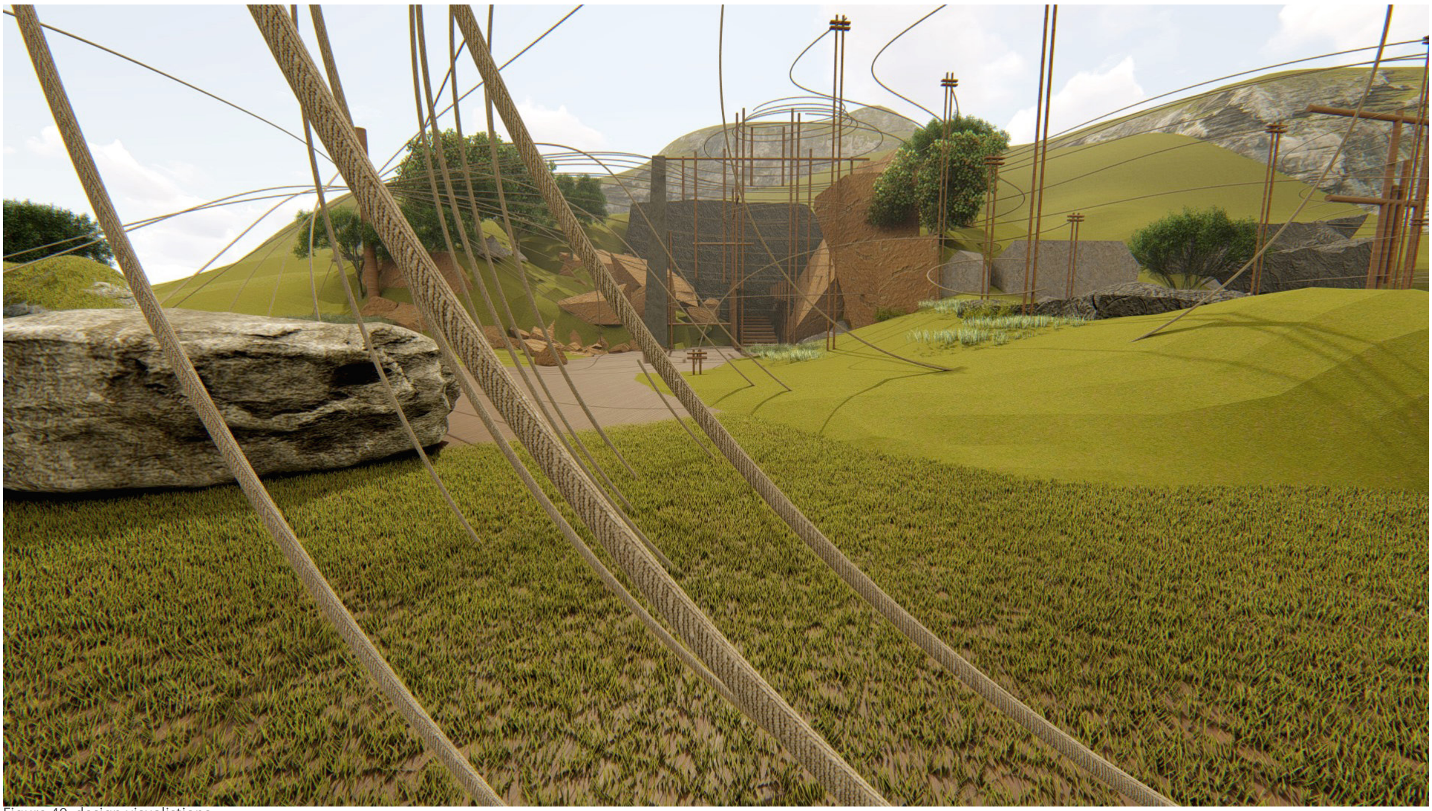


Figure 49, design visualistions

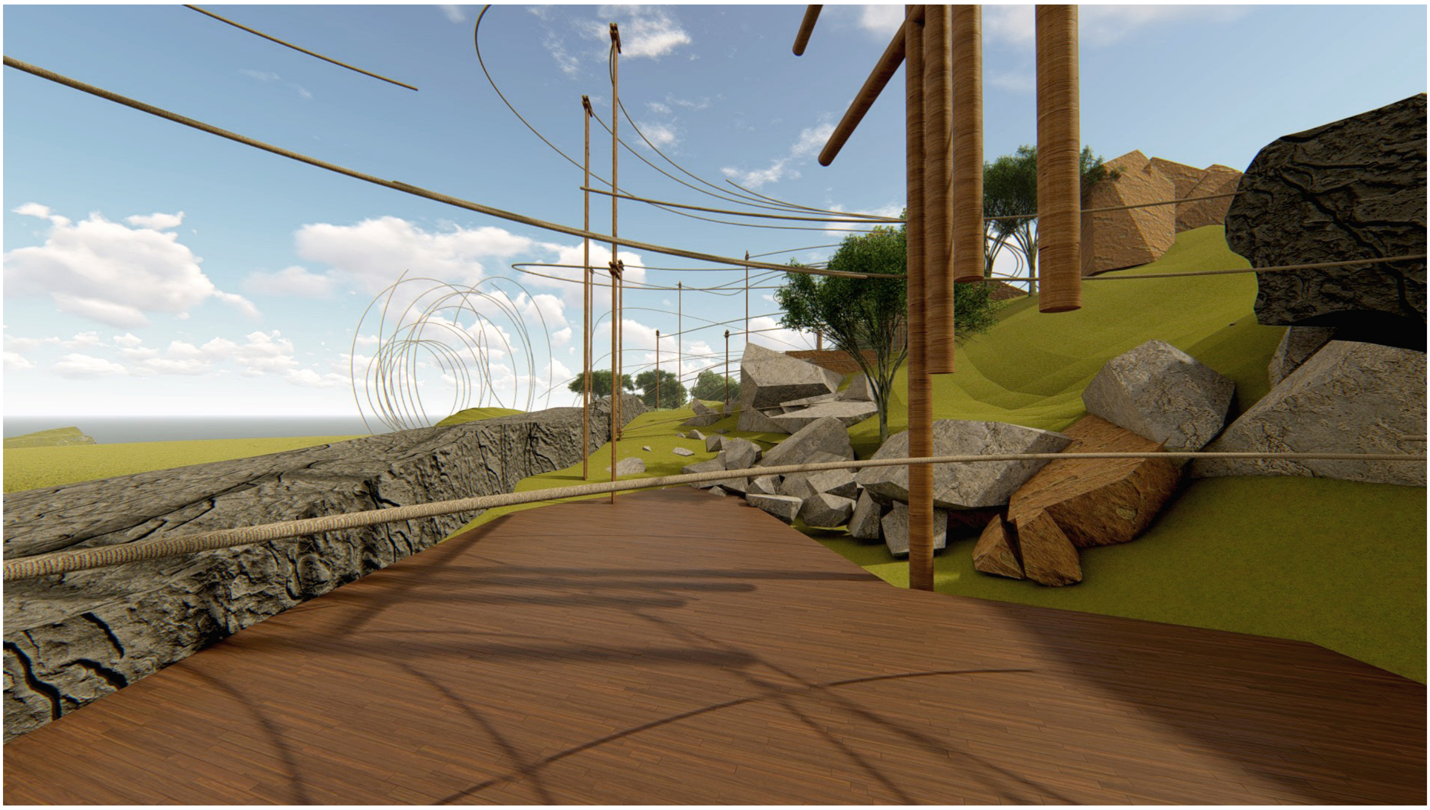
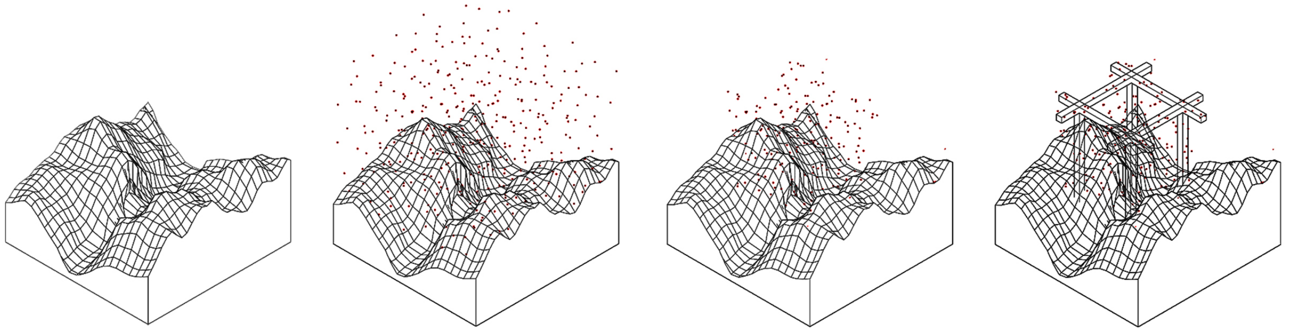
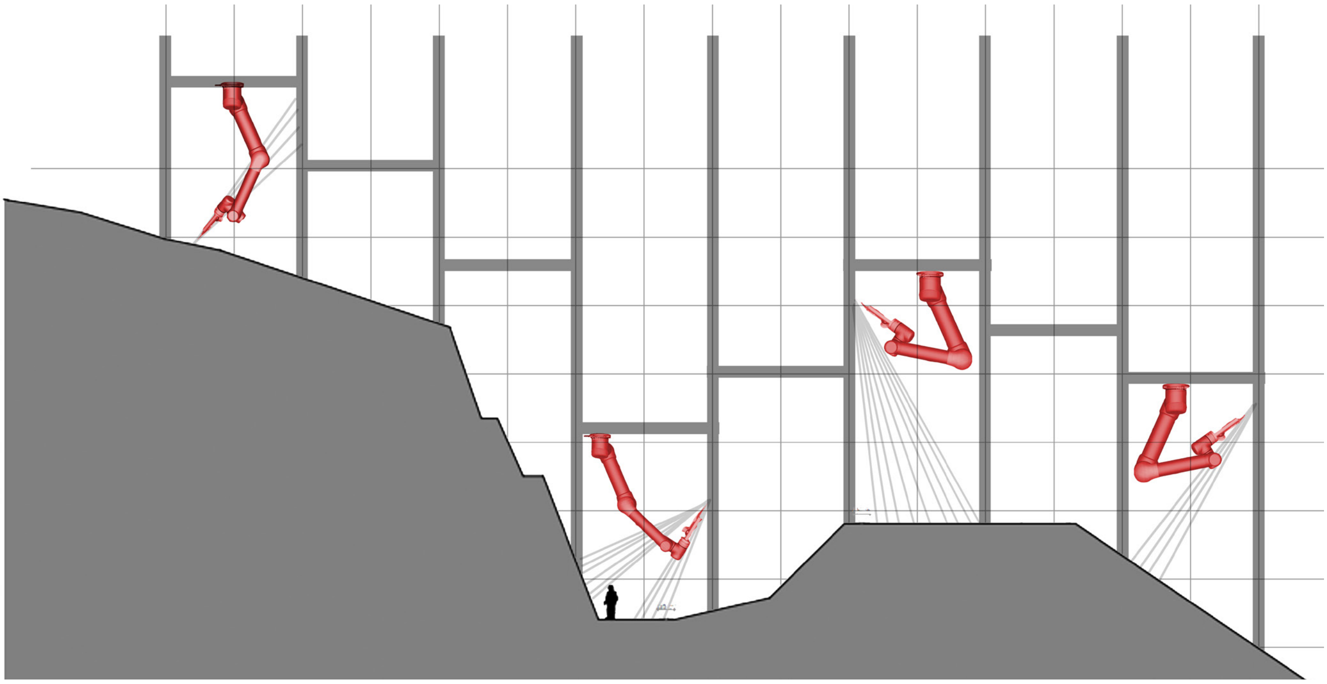


Figure 50, design visualistions

9.4 Construction design

IAs this process is new and involves using a robotic arm as its primary fabrication process a completely new construction design was speculated, to have a maximum operating range of the robotic arm it was decided to fix them upside down on a selected quadrant in the site. The illustration below describes how this construction process can be adapted for an interactive robotic fabrication process.





9.5 Technical drawings

To convey the working environment of construction details to on-site workers a set of technical drawings is proposed which conveys assembly/ disassembly details for robotic arm and steps to set up a work environment. Drawing and details for this part of this thesis will be developed during P5

10. Conclusion

Design tool and workflow presented in this master thesis allowed a robot to work on a task where complexities like interaction and tool development otherwise proved prohibitive. Experiments were carried out in a relatively controlled environment of a research lab rather than on the considerably more complex on-site environments it is intended to work within, the success of robot weaving selected material based on generative curves received grasshopper script demonstrates promising proof of concept. The use of a tactile rope-like material and a strong adhesive will eventually allow robots to develop built spaces developed collaboratively with the architect. It also demonstrates how the crafts typically achievable by human workforce can be executed using human-machine learning and robotic weaving tightening the gap between past and present and future. The speculations and practical implications of this new process are beyond the scope of this paper.

This paper also speculates a programming software which allows an individual to interact with the process of fabrication and details out the different end -effectors required. This program introduces an idea of control where the architect can step out of the screen and evolve the design as he feels fit and the robotic programming learns from these changes adapting its output towards fabrication. Although the program is still in its speculative stages, a potential controlling platform is presented in this paper.

The Kinect camera, robot, and end -effectors which are not yet completely incorporated into the workflow offers an additional layer on data feeds, which includes live video feed, gesture controls and torque data from the robot. This could offer more information for robotic weaving to drive decision making for different generations of architectural families. For a more real-time adaptive process developing machine learning based on this program will be the next logical step, Which will lead to developing various new fabrication strategies and construction methods which are not only adaptable to unpredictable context behavior but can also integrate physical changes performed by the architect.

11. Literature Review

Literature research started with understanding the non-visual qualities of architecture and its phenomenology behind it. This research knowledge was then compared and assessed with studies on computer-aided design and digital fabrication. Studies on HCI, robotics, weaving, and current works in robotic fabrication helped in developing a framework for this research. The conducted literature review can be divided into 5 different aspects.

11.1 Architecture and Phenomenology

In simplest terms, Interpretive study of human experience can be coined a phenomenology. Situations like events, meanings, and experiences which occur spontaneously in the course of daily life are examined and clarified (von Eckartsberg, 1998, p. 3). The architecture of beginnings is not built by architects. This has an elementary character that points way back to nowhere and leads to a goal no one could reach. Instead, this kind of architecture creates a path on which we leave things behind us in order to recover them (H. Kukelhaus, 1972 Human beings experience things in a multi-sensory way which can be referred to as phenomena, description, and exploration of this phenomena can be defined as phenomenology. For phenomenological investigation topics such as Any situation, experience, event or an object that a person can smell, touch, hear intuit, know, understand, feel, live through or taste can be considered legitimate. As human beings perceive and feel, experience and encounter and live through there can be a phenomenology of color, of the landscape, of power of the economy of sociability, of home, of travel, of architecture and so forth (D. Seamon, 2002). Juhani Pallasmaa in his book "the eyes of the skin" states we have moved towards an ocular-centric architecture defining phenomenology of architecture as a lost element. Architecture should elaborate and communicate thoughts of man's incarnate confrontation with the world, the built environment should make the world which touches us visible to our plastic emotions and evokes other senses (J. Pallasmaa, 1996).

When a design of space takes precedence over the design of the object is when architecture is turned into art. Living soul of architectural creation is a spatial intention, planes which do not themselves have a character of an object but are born out of the relation between objects or boundaries define limits (P. Von Meiss, 1990).

This literature helped in understanding the philosophy of architects who design spaces, modern practice of architecture design, and how has it changed throughout the passage of time. Understanding the mind of an architects plays an important role in developing fabrication environment which is the product of human-machine learning and digital fabrication

Figure 29, FU-SPACE on the West Bund by Archi-Union Architects. source - Pinterest

11.2 Weaving

One of the oldest activities for mankind is weaving, there are two layers in a fabric called weft and warp, weft runs from side to side and warp runs lengthwise. The craft of weaving has been practiced from centuries and continues to evolve with the development of new techniques. The two elements warp and weft define the strength of weaving. In architecture weaving has been used since ancient times, different natural materials like bamboo, thatch, reed were being used traditionally to makes dwellings units. Hands-on weaving routines in craft-making and house construction are still widely exercised in several traditional communities where digital fabrication tools and advanced materials are not available (P. Oliver, 1997).

Weavers sense and logic perform an immediate problem-solving procedure while they are working with raw materials, as every weaving step is constrained by making a knot As Donald Schön illustrated about designers sketching their designs as a reflection-in-action practice is analogous with the activity of weaving (J. Bass, 1990). Thread used for weaving performs as receptive units and cutaneous appendages to transmit structural data which is generated when the thread is stretched and pulled from the weaver's hand during the process of weaving, during this process of weaving, the weavers joint, muscle and skin performs dynamic to act together with different degrees of sensitivity. The skin pressure provides contact information, angle and position coordinates are transmitted from joint rotation, the stretching muscles transmit stress and strain data.

Information regarding the weaving surface's stiffness is generated by the combination of these steps which project a vector space in the surrounding environment.

The review gives insights on the role of perception in computational design and architectural design framework while highlighting details on weavers physical tasks, and is an inquiry into one of many approaches to weaving and its use in architectural design, which is important in developing different end – effector tools for the intended fabrication process.

Figure 30, Wicker Structures by andrea von Chrismar, Source - Inhabitat

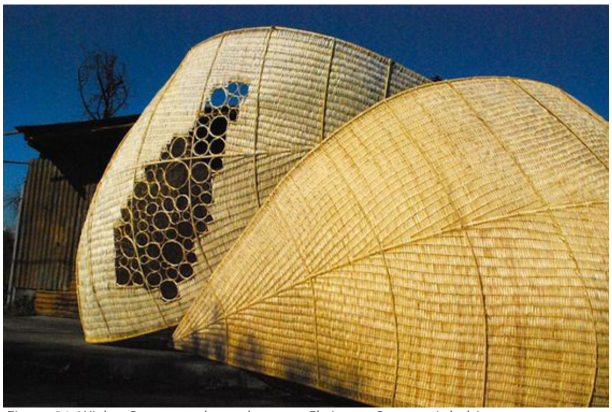


Figure 31, Wicker Structures by andrea von Chrismar, Source - Inhabitat

Figure 32, Interior project by SUEP, source-Inartstudio.com

11.3 Robotics in architecture

Use of robotics has been undergoing experimental changes where it is getting adaptive to on-site changes and a variant fabrication process, the review in robotics for architecture presents possibilities and ongoing research in different fields of architecture and constructions industry, it informs on working and limitations of robotics in architecture

Figure 33, KUKA robot used for large-scale 3D printing. Image courtesy of Branch Technology

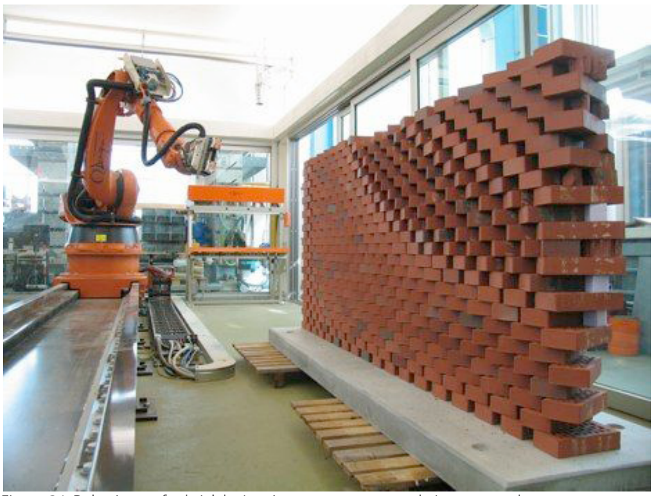


Figure 34, Robotic arm for brick laying, image source - google image search

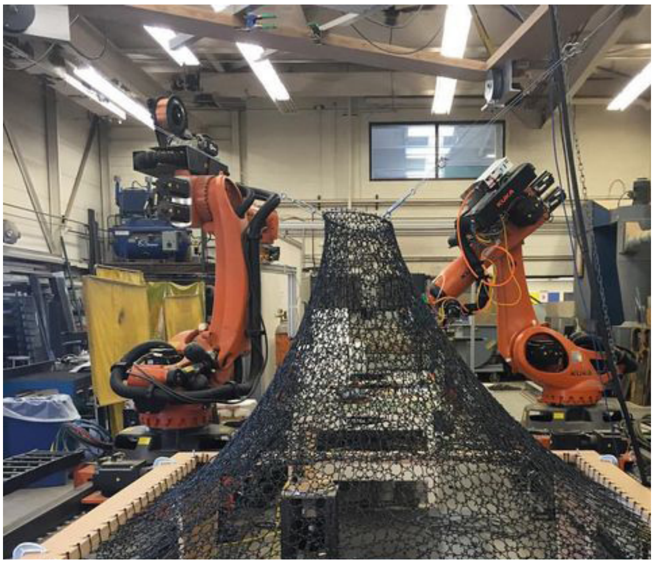


Figure 34, Robotic arm for brick laying, image source - google image search

11.4 Robotic weaving in architecture

There are several ways robotics can be used in digital fabrication for architecture construction, the process adopted for this research thesis is robotic weaving as it offers opportunities towards adaptive fabrication process. Notable research in the field of robotic weaving was reviewed to understand the possibilities and limitations of this method, research studies carried out by the University of Stuttgart were greatly influential in developing a framework for this thesis. Working examples of pavilions developed for ICD/ITKE from the year 2015-2017 were studied and analyzed to understand the process adopted for using robotic weaving as a tool of fabrication.

Figure 36, Carbon Fibre pavilion, University of Stuttgart

11.5 Technical know-how of the robotic arm used for this research

Initial experiments using UR5 (series of the robotic arm used in this research) were carried on a standalone softer called RoboDk which is also compatible with rhino yielded comprehensive information on technicalities behind robotic programming. An in-depth details study was obtained from RoboDk guide which is available on their website, the following is the overview of different technical aspects pertaining to UR5.

- Reference Frames - Location of an item with respect to another item with a given position and orientation is defined by reference frames. An object, a robot or another reference frame can be defined as an item. Simulation for the robots an updated by an offline programming application which defines the location of the object

- Tool center point - The robot Tool Center Point (or TCP) is the point used for robot positioning in any robot program that involves targets defined in the Cartesian space. The TCP is defined as a transformation from the robot flange. For any robotic application defining the right TCP is important as it informs the robot of tool limitations.
- End Effector - End effector is a tool which is attached to the head of the robotic arm, it's basically a tool designed to perform desired task, different end – effector can be fabricated to carry out the assigned task.

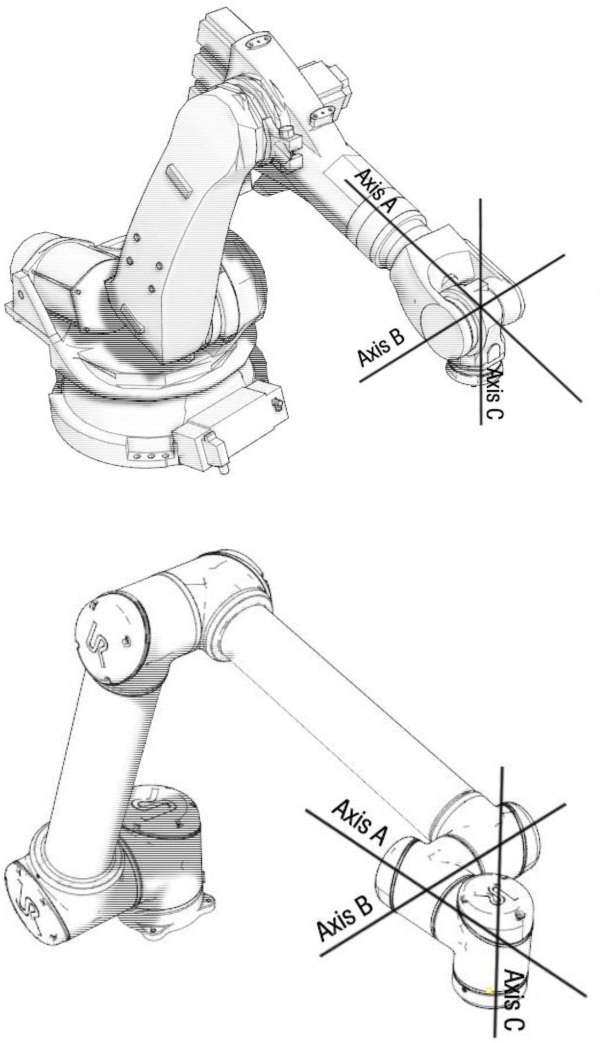
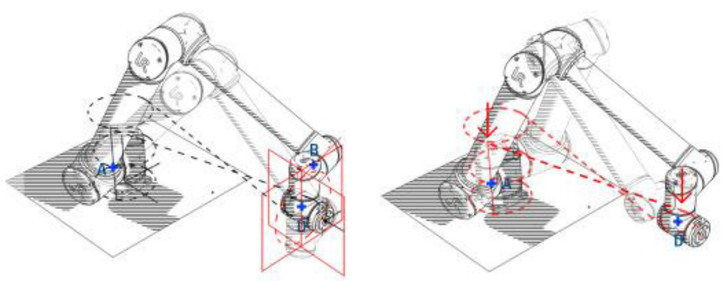


Figure 37, Axis orientation of the robotic arm, source - K. Elashry, R. Glynn



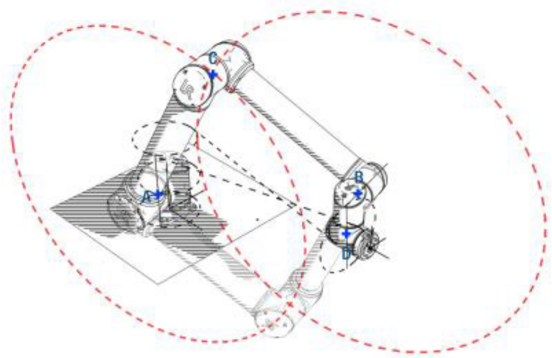


Figure 38, The nine IK solutions for the universal robots, source - K. Elashry, R. Glynn

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