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Conceptual Manipulation from Design to Production-Case Study of the Winner Project at Optima+ International Competition & Digital Fabrication Workshop

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***Abstract**:*
The main goal in this paper is highlighting computational parametric form generating tools dominance on the contemporary design to production process , and how it affects the designer aesthetical and functional decision ,by analyzing the ability of conceptual manipulation through the design process to the last production stage and testing the design process Parametricism ,while maintaining the design initial specifications , also discussing the accompanying design methodology choice between form making and form finding and how far can the designer use benefits of both methodologies through the case study of the winner project of the International digital fabrication workshop & competition (Optima +)

Keywords: *Computational design, parametric design, Mass customization, Digital fabrication, form finding*

1. Introduction

In the digital contemporary architecture era & the rapid and major dominance of parametric design tools on the architectural product, to reach towards the utmost liberation to the conceptual design thinking resembled in free forms that could be tangible in the real world space with its specific production and fabrication coordinates , these parametric tools make it easy to control and manipulate the design output not only through its design development stages , but also to the last moments in production process these new digital parametric potentials gives more flexibility to the design process and it makes the innovation ,continuity , diversity, communication , expansion and propagation develop infinitely turning all design products and especially architecture into living interacting creatures, what boosts these new design potentials is the digital revolution in programming paradigms accompanied by the revolution in digital fabrication means including CNC machines and robotics .

Although; it remains some doubts about the real design control measure between designer & digital tools in design and fabrication, does the designer optimally use these digital tools to achieve his aesthetical vision or he is just mimicking and simulating these tools capabilities from the beginning unaware to the uniqueness that his design output should be?

And how far do these tools provoke a new architectural and design style on a real deliberate principles, or that this similarity is due to the unconscious digital tools control on the designer imagination?

This paper is in reach to answer these questions, through the case study of the PEACEFUL BREATHING PAVILION (the winner project proposal) designed & fabricated in the OPTIMA+ digital fabrication workshop & competition.

- sponsored by:(Iaac < Institute of Advanced Architecture , Barcelona ,Spain & Sharabassy architectural consulting office,Egypt)
- Fabricated in: (Iaac green FabLab in Valldaura labs ,Barcelona, Spain)
- Designed with: (Dina Shams –Mariam Fahmy-Y.A)

2. Method

The main goal is to prove the dominance of designers mind over digital parametric design and fabrication tools , and to prove that the aesthetical design product is judged only by the designer , not the flexibility limitation in used tools , highlighting some concepts and connotation of related terms to the research at the beginning , followed by the analysis of OPTIMA+ workshop winner project design process .

3. Conceptual Form

The understanding of form concerns an overlapping relationship of geometrical (aesthetical) and perceptive (psychological) concepts. (1) As form is the first perceptive element that leads to the understanding of the architectural organism. From this point of view form becomes the key communication tool of the content of space.

Form in architecture certainly cannot be separated from the process of form generation and conception. The form generation in architecture is conditioned as an interdependent relationship between two parameters; the aesthetical and technological ones, so it can be defined as a process that balances the intangible feature with the materializing aspect.
The design process has become more complex through time and its evolution has naturally affected the form generation, the form generation is also conditioned by the preliminary modeling process. This is the reason why knowing and understanding the limits of form is to explore its means and possibilities of expression (1)
This necessitates that architects should learn a new language involving new machines and new software. Understanding materials, machine capabilities and design becomes imperative for the digitally conscious architect for the present and future generation.(2)

- Experimentation in Form Generation
  - experimentation in form generation OPTIMA+
  - Design procedures
  - (Manipulating concept)(OPTIMA+)
- Tectonic Shift to form Follows Technology of Design
  - Optima + to production optimization
  - Design to production
- Conclusion

3.1. Experimentation in form Generation

The introduction of new design techniques in the last decades, gave opportunities to design very complex geometry objects, what with precision may be created only In computer version. architects began to use new techniques which are commonly used in other fields. The first technique, which has made a quantum step in architectural design, is form parameterization. In contrast to the completely manual method of creation a three-dimensional computer model, in this case the object is created on the basis of equation (parameters) between its elements using mathematical method, described equations between. This method seeks to create a graph hierarchy where the location, shape and size of some objects are dependent on the basic elements. This gives the opportunity to create a model in which modifications in the geometry of the initial phase of design modify an entire model from beginning to end, Programs which are using to parametric design tools are extremely precise and require very precise construction of the model. (3) This method is called parametric form making as it interprets a previously determined concept.
A more complex approach to design presents a method of creating generative architecture. In that case, the architect becomes a architecture programmer”. Using advanced algorithms, designer describes how to create object that is shape which finally is generated by the computer. Shaping an object form, is done only at that level, which was determinate at the beginning by the architecture , Development generative design is design of evolutionary, with to the objects created by algorithms added aspect of the possibility change it over time. In other Words: the principles with creating forms, rules are modified during over time due to external factors. We are able to predict result of generative algorithms, problem is. In the design of evolutionary. We rely on only on interactions made by computer with that case include so many factors. The end result is very difficult to determine before starting the simulation model of evolution.(3) And that is called the form finding process ,
Form finding rely on three tectonic approaches: structural first, material first, form first,

- Structure-first is an approach to form-finding in which the morphological principles of classes of structures are the basis upon which the model is established. Pre stressed syclastic (or anticlastic) cable nets or membrane structures; lattice shells and lattice domes; two and three-dimensional lattice structures; and branching (tree) structures are examples of such generic forms of light- weight structures. The definition of the sub-classes of each class enables the beginning of the modeling process.
- Material-first is an approach to form-finding in which the material may be selected in order to analyze and establish structural principles. The soap bubble and wire frame models or the fabric membrane models which were used to study minimal surface structures were classic examples of material-first form finding.
- Form-first form-finding defines the case in which certain geometric factors of form have been established early in the design process and thestructural principle and material must accommodate the form. It is also possible to state that at some point in the design process after establishing an overall form, detailed models are employed to analyze decisions of structure and materials. (4)

In proceeding experimentation in form generation one or all of these previously explained approaches could be used, Although the main vital approach for form generation experimentation is the form finding approach . at this point another conflict could appear in the design process which is the mixed understand between form and concept , design process always begin with a concept weather using up-down method or bottom-up method, this concept is then interpreted to architectural container that is expressed by the form, for so , the Peaceful breathing pavilion analysis will begin with conceptual analysis followed by experimentation in form generation .

<u>3.1.1. OPTIMA+PEACEFUL BREATHING Design Concept</u>

The design concept was to find a cultural common symbol, the world peace dove symbol , the delicate Volant dove flying motion was studied and analyzed to phases, these phases of motion was extracted from an aerodynamics research discussing the flying motion of a bird , the smooth line the dove draws in flying between the beak and the bottom was translated into the smooth design of the PEACEFULL BREATHING pavilion incorporated with satisfying specific parameters which were the specified area of the pavilion 5 meters width by 5 meters length with an average height up till 3 meters . the function required, which included a shaded comfortable resting zone with a seating area and a shelve for different usage and a fun area with playful elements , also fitting the concept into the fabrication material which was medium density fiber board with maximum length 3 meters ,all these functional requirement had to be maintained through the design process .

At this point a specific concept with determined functional requirements is clear to begin form making or finding process ,

- Form Making or Form Finding

As a matter of fact a mixture between the two approaches was used , it could be said that form making approach was used as we used a bottom up design method , there was already a previous conceptual form needed to be put in order to satisfy the functional requirements so this could be called almost form making , but when trying different iterations still in form to manipulate functional form , in this case we are determining the form from the total functional parameters that should be satisfied , and that is form finding (5)

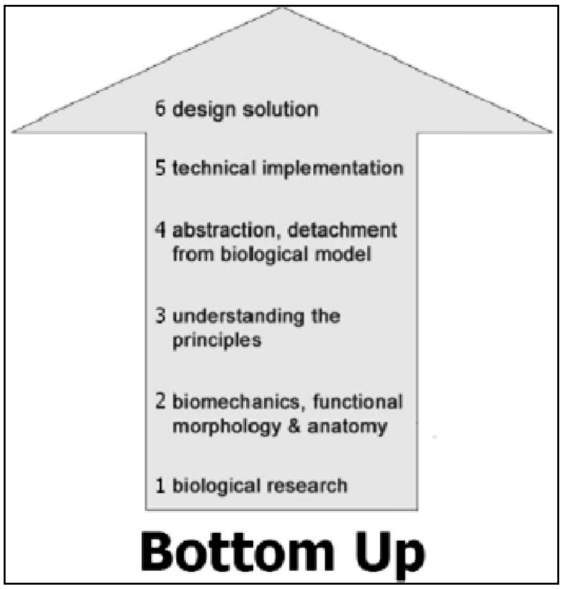

Figure 1

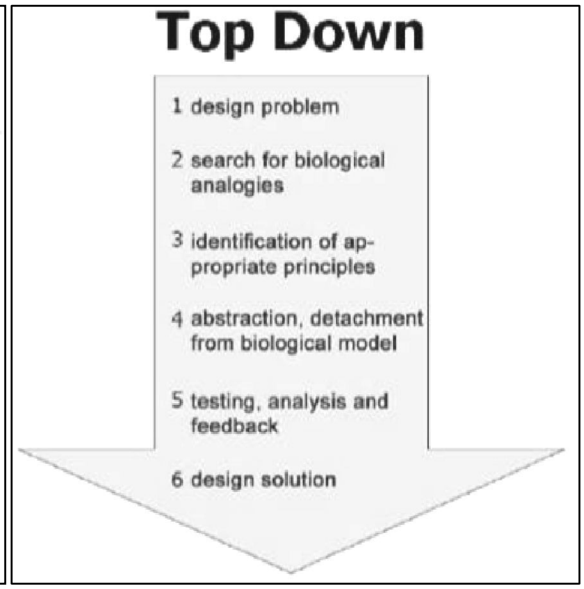

Figure 2

The form making began in Rhinoceros modeling software to outline the imagined conceptual mass , the team had four curves to loft a ruled doubly curved surface , and so began to manipulate these curves control point to locate the total pavilion mass in the boarders of the specified area , trying to achieve as much functionality as possible .

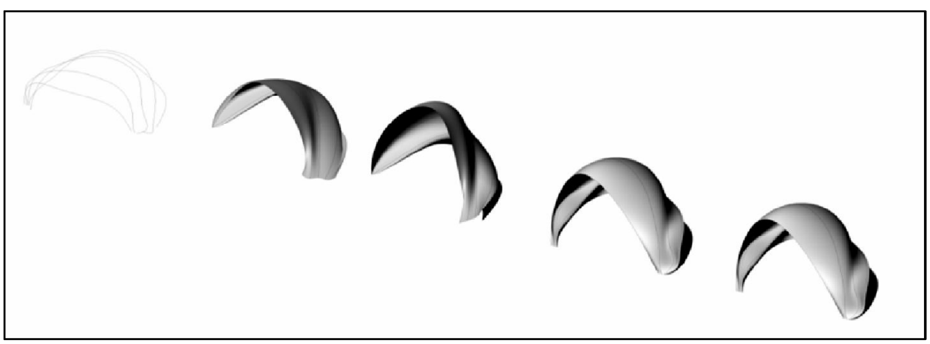

Figure 3

Diagram shows the form manipulation throw manipulating the main four curves created in RHINO 3D modeling and referenced to Grasshopper to be lofted

Finally an appealing form with a fully satisfied function was generated, on the third day of the five days period phase one held on Cairo, Egypt, this Phase was one of the two phases of the OPTIMA+ workshop / competition.

Then the pavilion fabrication strategy had to be determined as it affects the resultant form,

- Digital Fabrication Strategies

Digital fabrication is defined as computer-aided processes that manipulate material through subtractive or additive methods. These processes can be broken down into two groups: computer numerical control (CNC) processes and rapid prototyping (RP) processes. The fundamental difference between these two is that the CNC processes create objects by removing material (subtractive) while RP processes create objects by building it up layer-by-layer (additive). A few examples of CNC processes are milling, water jet cutting, and laser cutting. RP processes include three-dimensional printing, stereo lithography, and fused-deposition modeling. (6)

- 2D Fabrication Techniques

The production techniques used in 2D fabrication often include

i. Contouring.
ii. Triangulation (Or Polygonal Tessellation).
iii. Use of Ruled, Developable Surfaces.
iv. Unfolding.
v. Waffling

They all involve extraction of two-dimensional, planar components from geometrically complex surfaces or solids comprising the building's form. Which of these strategies is used depends on what is being defined tectonically: structure, envelope, a combination of the two, etc.

In contouring, a sequence of planar sections, often parallel to each other and placed at regular intervals, are produced automatically by modeling software from a given form and can be used directly to articulate structural components of the building, as was the case in a number of recently completed projects. Complex, curvilinear surface envelopes are often produced by either triangulation (or some other planar tessellation) or conversion of double-curved into ruled surfaces, generated by linear interpolation between two curves. Triangulated or ruled surfaces are then unfolded into planar strips, which are laid out in some optimal fashion as two-dimensional shapes on a sheet (in a process called nesting).

To the Peaceful breathing pavilion ; the best fabrication solution was the Contouring, as it keeps the surface smooth , it won't have many joints and connectors ,and it won't affect the design stability . At this phase the proposal of the form aesthetically and functionally satisfying and the chosen fabrication method contouring were ready.

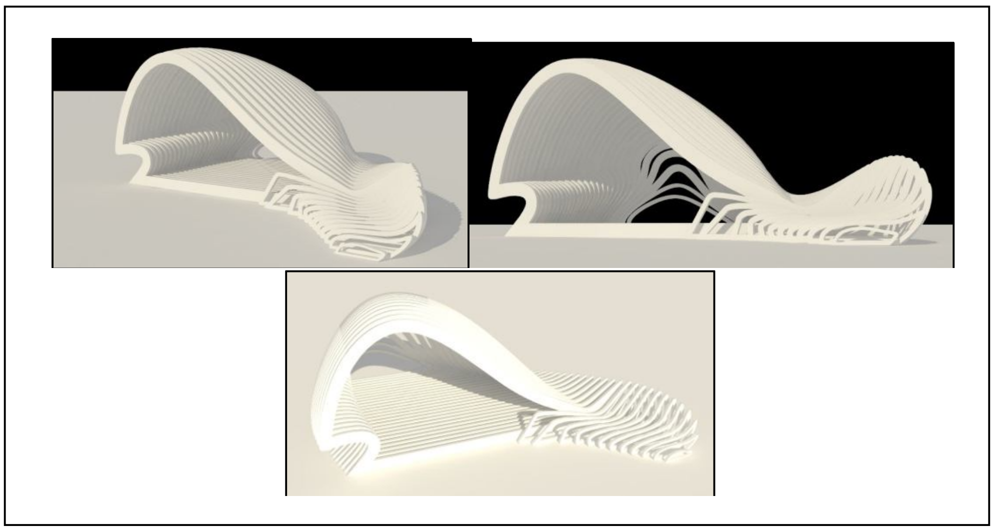

Figure 4: The rendered pavilion proposal with the countering fabrication method

3.1.2. Design procedures in OPTIMA+ (PEACEFUL BREATHING) pavilion

Reaching this point ,there was a clear order to the design procedures the BEACEFUL BREATHING pavilion had , the four initial curves in Rhino that generated the surface was inserted to grasshopper to make it parametric , specifying the contouring direction in the y axes to generate profiles that are able to be nested in the MDF boards dimensions , the team specified the contouring profiles number , thickness ,width and height, then the team designed a joinery system based on tangential tight rods that penetrates the countering profiles of the pavilion to fix them together without affecting the form smoothness, and a bolt not joinery to fix the pavilion profiles into the ground, and to further stability burying the bottom parts of all profiles in the ground .

3.1.3. Manipulating concept) (OPTIMA+)

To experiment the environmental circumstances where the pavilion will be built , an environmental simulation software was used (Ecotect) , the pavilion was planned to be built in the GREEN FABLAB in Valldaura Labs –Iaac , Barcelona, Spain .

So the pavilion was located on the planned site by the simulation tool, to calculate the site climatic conditions: temperature through four seasons, wind direction and velocity, sun radiance, etc.

one more step to experiment the PEACFUL BREATHING pavilion proposal ,was the primary prototyping to test aesthetical appealing , dimensionality, functionality, stability and fabrication preview

- Prototyping

For the experimental rapid prototyping of the model , a simple subtractive fabrication methods was used, the pavilion contours were nested in scaled acrylic sheets , organized and labeled by numbers to facilitate the assembly process , a laser cutter was used to cut the nested acrylic sheets. The prototype reflected the conceptual design and the fabrication strategy of the Peaceful breathing pavilion .

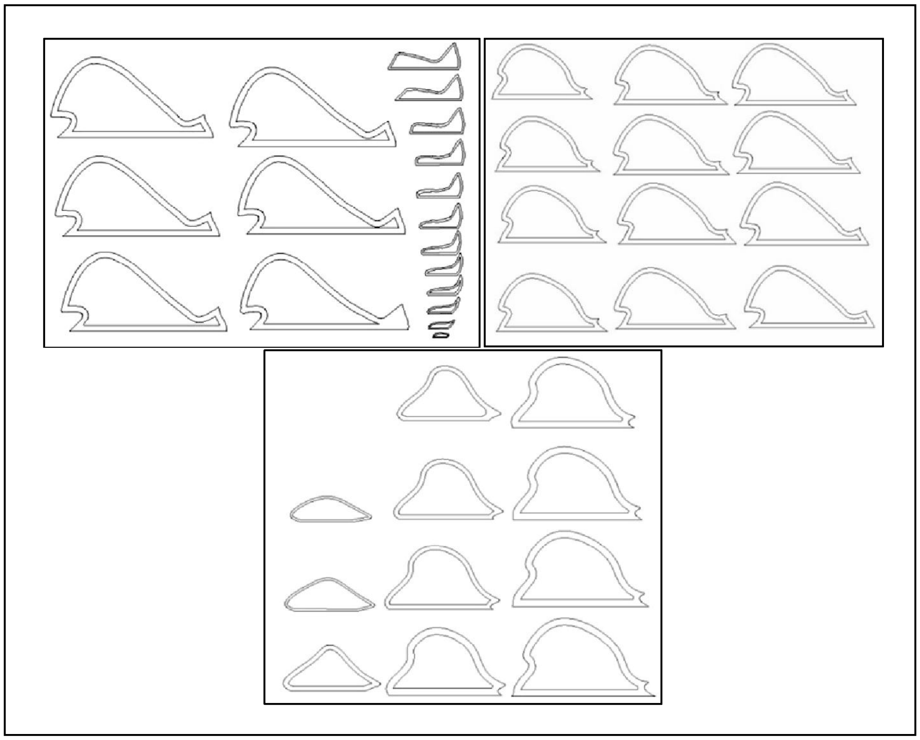

Figure 5: Prototype nested boards (scaled model)

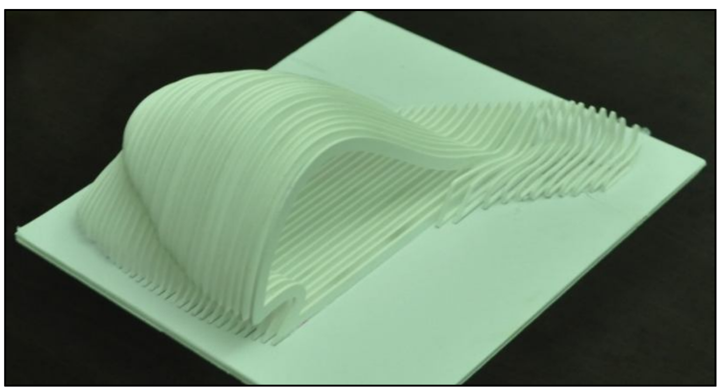

Figure 6: The PEACEFUL BREATHING pavilion prototype

3.2. Tectonic Shift to form Follows Technology of Design

the hierarchal relation between form and technology have always been a contentious issue , due to the gap between designer imagination and fabrication limitations ,thankfully these limitations have been reduced with the emergence of digital fabrication strategies directed and controlled by the continuously developing digital parametric design tools , that helped in materializing the most free form non Euclidean geometries into tangible reality , these tools and strategies have opened many options and possibilities in interpreting the architectural free forms through specific production and fabrication techniques ,unfortunately these specific production techniques seem to imposes new rules and controllers over the conceptual form , as the one encountered by the peaceful breathing team ; to choose a certain fabrication strategy that least affect the form and achieve stability , durability ,and strength , this balanced equation isn't a new require for the design process , it has been an essential procedure in the design process for ever , it could be said that this equation began to be easy to solve utilizing the new digital fabrication facilities to reach the utmost optimum formal and production solution through control and collaboration strategies .

- Control & Collaboration Strategies
  1. Geometry is created as a shared 3D virtual as opposed to a set of annotated drawings.
  2. Geometry is rule-based and parametrically constrained, so as to encode materials and assembly methods.
  3. Geometry is linked to an integrated database, so as to enhance collaboration.
  4. Geometry is rationalized, segmented, and ordered for physical assembly.
  5. Geometry is sent directly to Computer Numerically Controlled (CNC) hardware for manufacturing.
  6. Geometry is translated and transferred digitally, thus avoiding interpretation errors. (7)

These control and collaboration strategies between the design team and the fabrication team made it more easy and controllable to maintain the design characteristics through the production process, and enabling the design parametric control over its different variables in relation with fabrication constrains.

3.2.1. Optima + To Production Optimization

In OPTIMA+ phase two, the PEACEFUL BREATHING pavilion was chosen as the winner project to be fabricated in the real scale (1:1) , optimization here could be named ***production optimization*** , as discussed previously the tectonic shift to form follows technology of design. actually the fabrication or production optimization process applied on the PEACEFUL BREATHING pavilion , was optimizing the structure stability , physical resistance and turning the pavilion into living system able to grow , extend and produce .

5 days duration to design, experiment, executes fabrication of the PEACEFUL BREATHING pavilion, to accelerate and ease the fabrication phase. it was obligatory to deal with some code share difficulties:

- Anticipating flexibility can be difficult: maintaining the parametric nature of the design model through the fabrication stage could be difficult, as the design process gets restricted every time it moves to words its end ,to anticipate flexibility the four teams resorted to continuous prototyping and experimentation in every design stage to guarantee that no unpredicted sudden fabrication issues would show up in the last minute .
- Changes can be hard to see visually: another issue is to actually recognize the design modification in different stages especially in the fabrication process, as it is proven that a designer may not recognize fine modification on the design model when working intensively on it, here the four teams resorted to reciprocal data sharing to review the design model and the fabrication and joinery logics.
- Reusing and sharing models is problematic: while sharing the design model in the previous point was an advantage it is a disadvantage in this point, sharing design model would be problematic due to minimal fine modifications that could be add every time it is reviewed, so a high degree of concentration and conscious is required, also a tightly bonded close and organized workflow between different teams is also essential to overcome this difficulty. (8)

Before proceeding in the fabrication process; the four teams had to work collaboratively on two production optimization concerns:

i. the physical resistance and stability
ii. turning the pavilion to a living system

i. The Physical Resistance and Stability this optimization process was concerned with the joinery methods that would achieve the following points :

- Resist the winds velocity and direction, to manage more stability to the pavilion as its profiles had a large span in length and width.

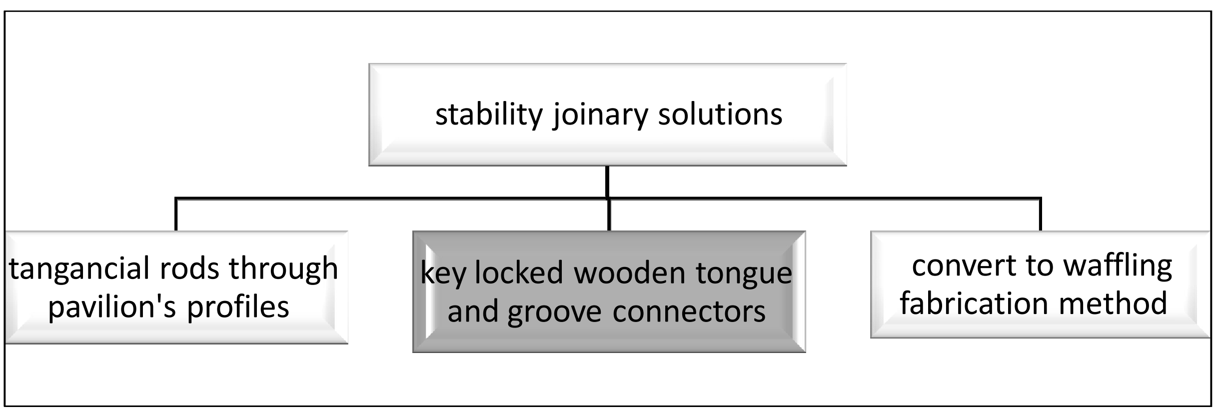

Figure 7: Suggested Joinery

The selected solution for stability and profiles connection was a designed key locked wooden connectors inspired by the traditional tongue and grove joinery , these wooden connectors dimensions was accurately computed equal to the y axis distance between each two profiles : 11 cm . Each key thickness was the same thickness of the used MDF boards , 1.6 cm which was cost effective as the maximum use of the MDF wooden cutting boards that the pavilion's profiles were nested in these key locks guaranteed the maximum stability as it didn't just relay on the tongue and grove strong joinery but it added the twist closure that fixed the connectors in place deterring them from the least tremble .

These key locks should be shifted in x, y, z axis the y axis direction is as it shifts from between two profiles to the another in between two profiles , the z axis direction is due to the increasing height moving in the y axis through the pavilion, and the x axis direction because we can't fix two penetrative key lock connectors into the same grove opening , so the key lock wooden connectors were organized in a brick like distribution design .

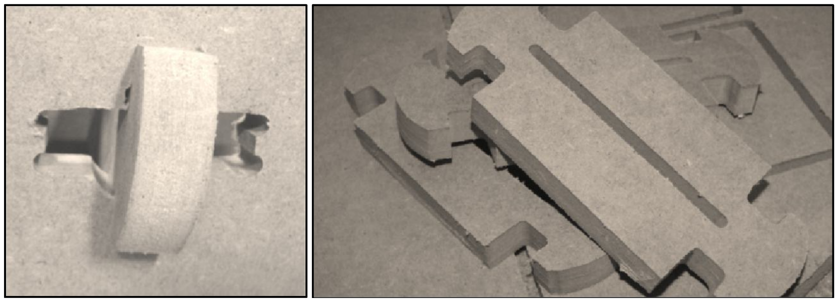

Figure 8: The photo shows an experimentation on the accuracy of the key lock wooden connectors

- The large length span in pavilion profiles indicates division to these profiles as it exceeds the MDF total dimensions, so we needed to find a joinery method to join the one profile parts.

a puzzle dove tail planer on the perpendicular direction on the x axis was used, this puzzle dove tail joinery could fairly hold the parts of each profile together enough to give the assembly team the time to connect every two profiles together with the key lock wooden connectors, these puzzle dove tail joints designed according to two specifications; the first one is to consider the material cost effectiveness while nesting the cutting boards. The second is the distribution of the puzzle dove tail joints not to overlap with the open groves of the key lock wooden connectors and not to be too close from these groves in order not to weaken the overall structure.

- to achieve more stability and resistance to wend velocity, the pavilion needed a pedestal foundation system to hold it tight to the ground

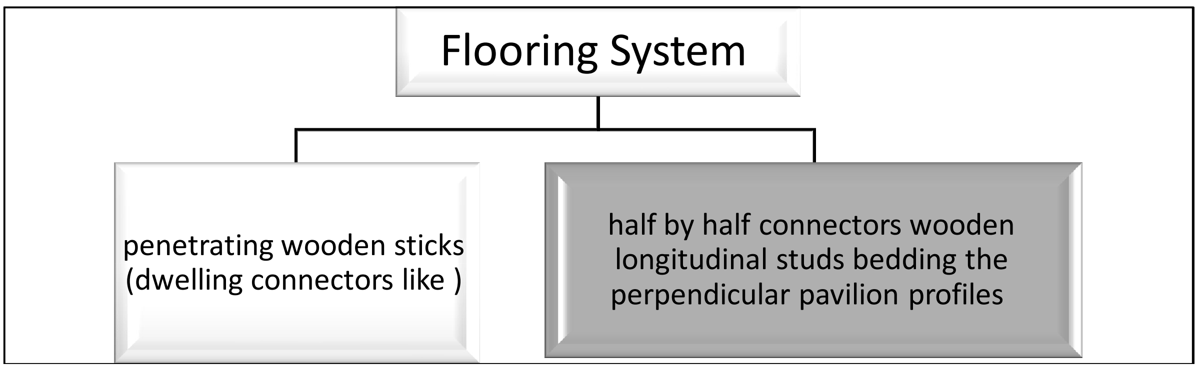

Figure 9: Suggested Flooring Solutions

The bedded shifted half by half wooden longitudinal board connectors maximum length was 1 meter, these 1 meter boards was designed not to overlap with the puzzled dove tail joints in each separate profile, and shifted from each other.
The half by half cuts in each profile were calculated accurately with 0 tolerances to fit the used MDF boards thickness 1.6 cm. and also distributed carefully not to overlap with the dove tail puzzled joints. after building the pavilion the flooring part was suggested to be buried in the ground up till its surface of the profiles in an added value to the landscape design .

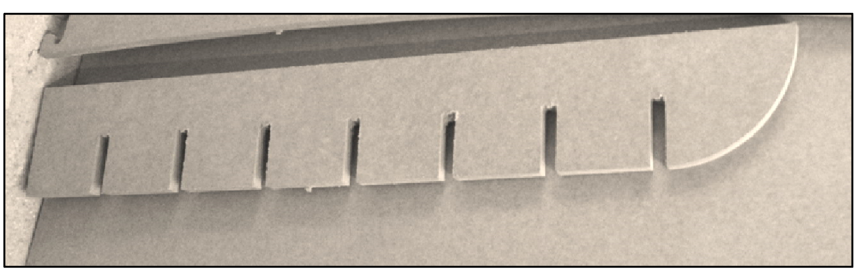

Figure 10: Flooring studs

ii. Turning The Pavilion to a Living System

In order to turn the pavilion into extendable growing system the skin design team had three main solutions

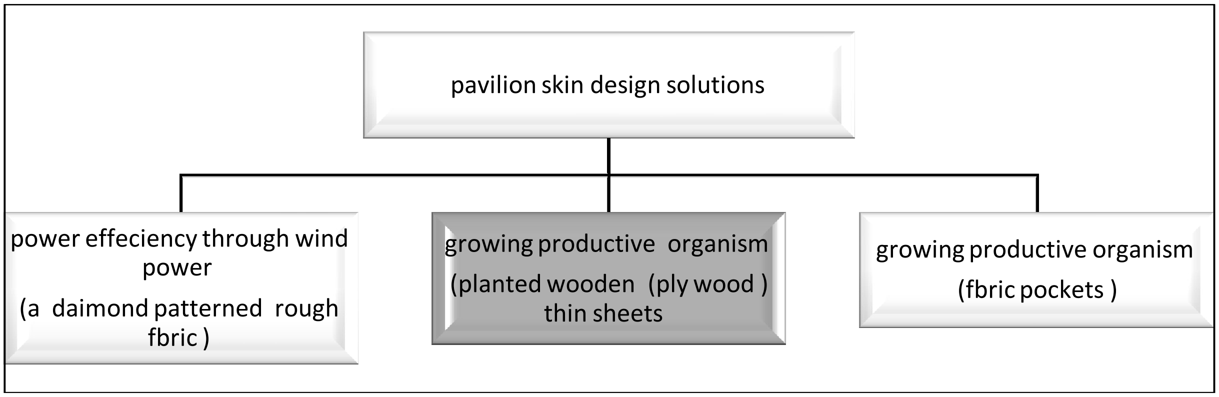

Figure 11

achieving living productive system through planting living organism on top of ply wood sheets fixed in the rectangular opening in the key lock wooden connector units which was a practical , easy ,cost effective and time saving solution .the ply wood sheets maximum length was 1 meter and they were distributed on the pavilion in between profiles randomly . the sheets were treated with special kind of organisms that can grow on any surface .

3.2.2. Design to Production

- *First Production Step (Preparing Files)*

At this stage it was required to make sure that the puzzled dove tail joinery of the profiles' parts don't overlap with the key lock tongue and groove joinery that connects the profiles with each other, also to make sure that the flooring half by half joinery don't overlap with the dove tail puzzled joinery so all the files were copied and shared between all teams to check it. after clearing the overlapping and reorganizing the joinery, then the nesting step was carried out , all the 3D drawings were turned to 2D to locate it on the nesting boards , to nest 26 main profiles the widest in span is 5 meters , and 13 small profile the largest in dimensions is 2 meters by 1 meter maximum , these were just the profiles with the key lock openings , the puzzled dove tail grooves and the half by half flooring openings ,then ,it was necessary to label the profiles' parts for the assembly process so every profile had two digits the first was a number and the second was an alphabetic letter for example (1A) , the first number says the order of this part in the sequence of joining the profile with the dove tail joinery and the second digit which is a letter says the order of the total profile among other pavilion profiles.
Also the teams had to calculate the number of key lock tongue and groove joinery wooden connectors to distribute them on the nesting boards, also number of the wooden studs for the half by half flooring joinery with locating half by half openings on them in the right place.
after nesting was complete the boards were located in 0,0,0 point to fit with the CNC milling machine settings , and a frame 1 cm by 1 cm in every cutting board was outlined to fit with the machine settings as well, after the completion of this step , a joinery extra experimentation was required to begin the fabrication process .

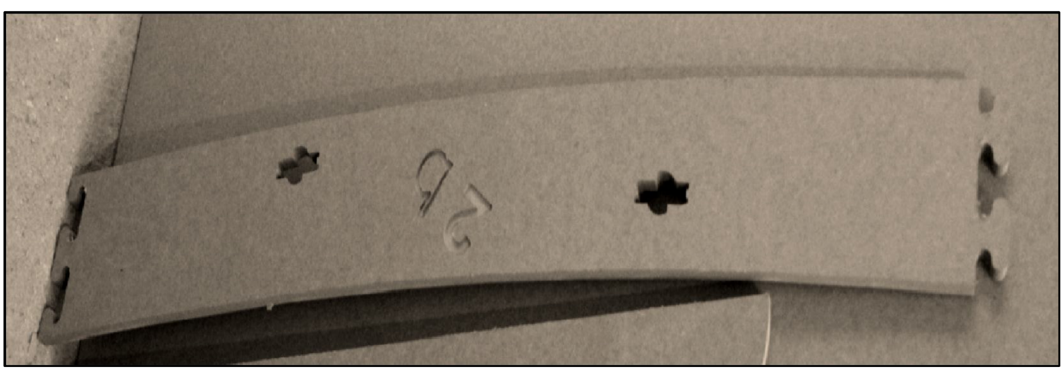

Figure 12: It shows the numbering of the profiles

- *Second Production Step (Experimenting Joinery Systems)*

to experiment all the joinery system , specially the key lock connectors; the teams cut a sample key lock connector by the CNC machine and small rips with the openings to fit into , and so we checked it and made sure it works properly not too loose or too much tight .

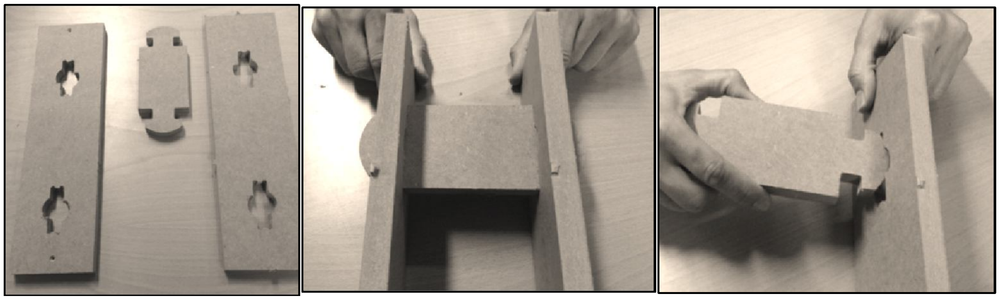

Figure 13: Shows the key lock joinery experimentation (in photo: Mohammed fayz (joinery team)

- *Third Production Step (Setting CNC Milling Machine / CAD-CAM System):*

Setting the CNC milling machine using the Rhino /CAM

- Main Programming Steps
- ⇨ Create the Stock geometry
- ⇨ Set the Machine zero point or Locate geometry with respect to the machine coordinates
- ⇨ Create / Select the tool used for machining
- ⇨ Set the feeds and speeds
- ⇨ Set the clearance plane for the non-cutting transfer moves of the cutter
- ⇨ Select the machining regions for containing the cutter to specific areas to cut
- ⇨ Select the machining operations and set the parameters
- ⇨ Generate the tool path
- ⇨ Simulate the tool path.

Nesting files were sent to the machine and reviewed. (9)

- Fourth production step (cutting boards / sanding / arranging boards):

While the milling machine was cutting the boards , this time was used in cleaning the cut profiles, sand them and arrange them every profile with its parts, that was quiet easy because each profile parts were nested in the same board, after the milling process was complete, all the profiles of the peaceful breathing pavilion were ready .

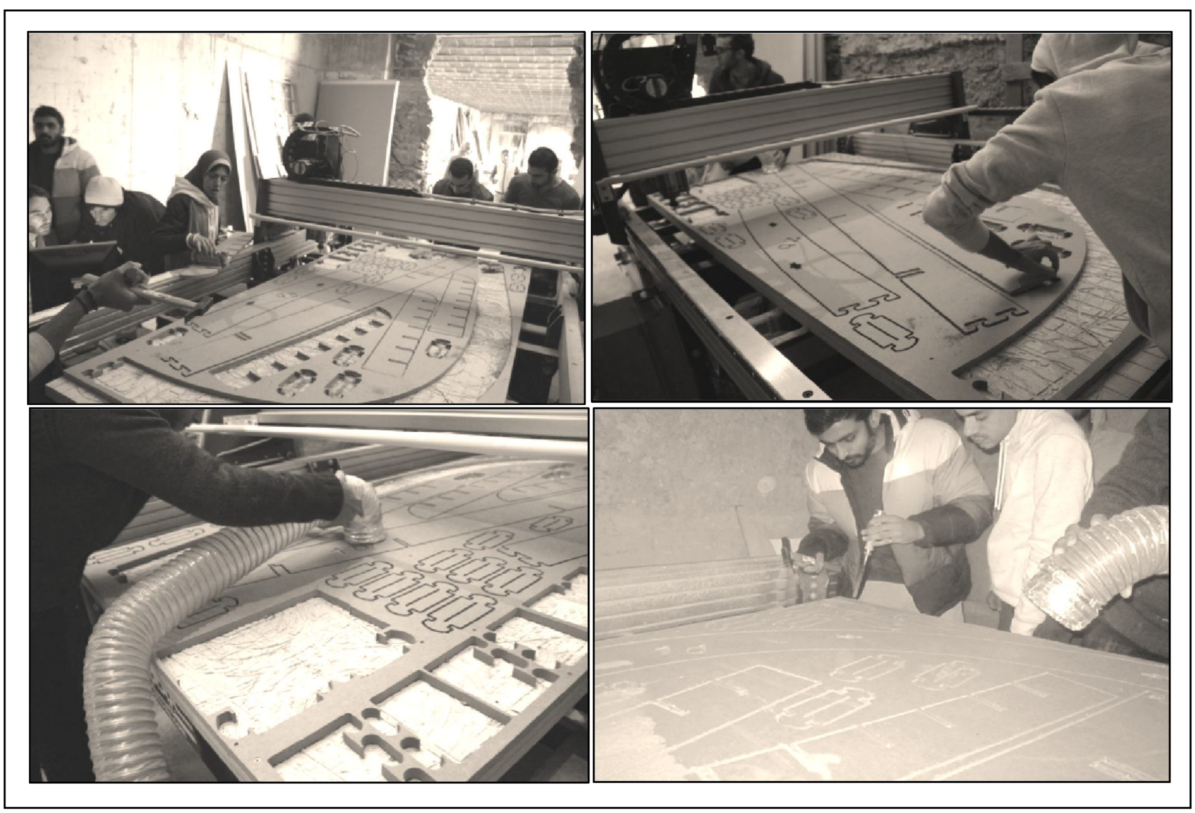

Figure 14: MDF boards CNC milling and cleaning, In the photo (from left to right) –(Jonathan Minchin : Valldaura fablab coordinator) , joinery team members ,and (ChirageRangolya : Instructor)

➢ *Fifth Production Step (Assembly)*

also the milling time was used to assemble the ready joined profiles while the machine continue to cut the rest of the boards , each profile from its parts first , as soon as three ready profiles were milled and sanded they were joined together with the key lock connectors .


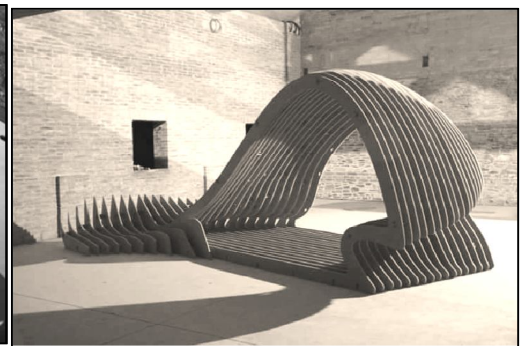

Figure 15: The completed assembled pavilion (photo by Ahmad Mohammed Ibrahim)

3.3. Discussion & Conclusion

a design chain is the procedural logical steps that a designer follow from the initial phases in conceptual form design to the finalist fabrication and production processes, the design procedures are concerned about parametric model thinking, how to build parametric interdependent relations between the design elements , and this is a quiet sophisticated meticulous process as it has many steps in understanding a models inputs , outputs , relations , interdependences and it may need some sort of front loading and software tools experience, ofcourse experimenting these difficulties range in an extrusive approximation with the model complexity , which was faced sometimes while developing the design to production in this case study, when moving to fabrication phase real problems started to show up, the main problem was the difficulty in Anticipating flexibility, trying to adjust the three joinery systems with each other not to overlap or intersect , in this phase many trails and errors were encountered, thankfully these trails didn't exceed the timetable pessimistic timing to the joinery design process, but actually time and effort sacrificed in this process affected the overall design chain , this time could have been used in further quality control and experimentation avoiding the last minute problems.

These last minute problems sometimes turn the design result to another unplanned and wanted concept as well, giving a deceiving aspect of parametric design tools fabrication techniques limitations, which is not the main reason for this design concept yield to accommodate the sudden problems and circumstances. Actually parametric design tools isn't even bonded with certain shapes or forms, the logic explanation of the formal almost uniform architectural designs is due to that these tools have facilitated the design process and opened possibilities for easy design to production parametric control to manipulate concepts maintain its essence , the key aspect is the knowhow of these modern techniques to gain its maximum benefits. This know how is tightly bonded with the design workflow or what could be called the design chain, the design chain is the main essential road map to every design to production process, it is the logic of the complete process, its importance is in the ability to deal with unpredictable problems, in the fabrication phase translating the virtual model to a tangible reality many un reasonable errors could occur suddenly & affect the aesthetical design decision which could mistakably thought to be affected by the limitation of parametric design tools potentials.

4. Acknowledgment

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