Symbiosis of Structural & Non-Structural properties in Building

Integrating structural behaviour in the generative computational process goes beyond instrumentality

Mania Aghaei Meibodi
Lulea University of Technology, Sweden
mania.meibodi@ltu.se

Hamia Aghaiemeybodi
KTH Royal Institute of Technology, Sweden
hamia@kth.se

ABSTRACT
This paper highlights the different interplays between structural and non-structural parts in building artifact as the result of modes of building processes and massing. The massing is understood as processes of assembling material into a body through which we identify with the building physically. In the last decade architecture discipline as the result of technological inventions has faced shifts in the design processes, massing processes and topology of the artefact. In which we witness integral coexistence between the structural and non-structural elements of building. In this paper the seeds of this integral interplay is scrutinised through the study of design and massing processes of a multi-functional pavilion prototype as a case study.

KEYWORDS: digital surface; prototype; design processes; structural; formation.

Throughout history, we see various interplays between the structural and non-structural parts of architecture. In the igloo the form of the structure carries down the load that is created by snow blocks as well as generating an optimized membrane towards wind and cold. In the ancient buildings the thick load bearing walls act as both membrane and structure. In the new structural principle of the gothic architecture the envelope perforates to achieve light and ornament becomes an integral part of the structural system. In the post and lintel principle of classical architecture, beam and post carries down the load while the wall and ornament as separate entities are applied as membrane and decoration respectively.

It is through the way and the type of massing that these different interplays between architectural inherent properties such as ornament, membrane and structure emerges. Through massing man assembles material to shape a building. It is through this massing that we identify with the building physically, so that we get a sense of muscularity, heaviness, lightness, vigorous movement, etc. On the other hand the modes of massing are tied to material innovations, production and construction technology. It is through the quantity and quality of matter, material composition and relation that an architecture body stands by a gravitational field, mediate the climatic forces, merges into a larger urban or natural context, and relates itself to human body.

Material and technological advancement of the last decades have revolutionised the modes of design and massing of a building. Computer technology has created the "ability to control fabrication digitally, to drive cutting, bending and assembling, to simulate and optimize material performance, to control geometry with precision" (Penn, 2011). The use of these technologies in architecture has followed a paradigm shift; we are witnessing a shift in design processes as well as a topological arrangement of the product. In this shift the topology, form and structure of architecture has been pushed to incorporate areas such as climate, acoustic etc; meaning the appearance of the product are pushed to incorporate the utilitarian aspects of it. A lot of work that emerges in the recent years of digital design processes of architecture seems to have been returned to the integral relation between structure and non-structure. One example is the Swiss Re Tower, in which the vertical tessellation of the diagrid creates the envelope. This diagrid, while being structural, is becoming an ornament and by holding the facade panels become part of the membrane. Other examples of such integral relation between structural and non-structural properties of a building are the Milan Fair Trade Center and the Kogod Courtyard of the Smithsonian American Museum. These buildings are different in their context but share a common language:

-The artefact is built out of heterogeneous parts or sub-parts and smooth transitions between them

-There is no trace of the hermetic Euclidean geometric figures or the role of order and proportion as described by platonic beliefs

-There is a seamless integration between ornamental patterns and utilitarian parts such as structure.

-Most of these artefacts are ornamental as a whole or are highly decorative in their formal appearance.

The aim of this paper is to analyse the massing and sequences of digital design processes to scrutinise the seeds behind the integral interplay between structure and non-structure, and common language seen in the appearance of their product. We use the case study of a multi-functional pavilion to fulfil this aim.

Case study of the multi-functional pavilion prototype

The 3.0 m wide, 7.0 m long and 2.6 m high pavilion emerged out of the nested hexagon cells with triangular joints on a double curved surface. Providing an enclosed space, part of the hexagonal structure is lifted from the ground to form a free-spanning shell. Breaking the North-East wind, it touches the ground topography and is covered by glass panels. To provide seating opportunities, the structure curls inward. In contrast to this part, the other end of hexagonal structure is narrowed in its width to cover itself from wind and is concaved to provide opportunities for lying down (Fig 1).

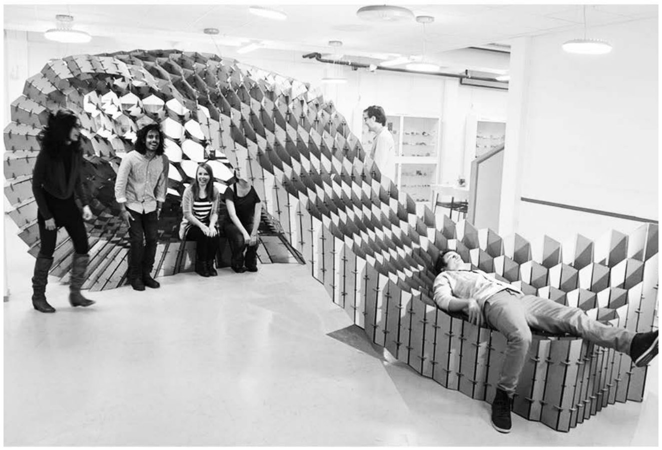

Fig. 1. 186-01, Picture of multifunctional pavilion prototype by Mania Aghaei Meibodi

The case study of multifunctional pavilion was originally carried out to study the relation between processes and appearance in case that there is more than one utilitarian factor driving the design. In the design processes different models had to be developed for a respective utilitarian driving force. The design to the production of the multifunctional pavilion prototype was guided by the following framework:

Usability framework was to design a pavilion that enables relaxation (sitting, lying, leaning or standing) in all seasons of a year and provide both enclosed and open spaces.

The available production technology was computer numerical controlled (CNC) laser cutting machine.

Possible material choice was Masonite 3.2 mm and 7.00 mm, hard density (HD) Masonite 5.00 mm, and plywood 6.00 mm. These materials were candidate in relation to budget and machine capability. They came in sheets of a certain size and with different thicknesses. To cut them, the laser tube had to be run with certain power and speed. In order to measure the time of cutting, the laser power was kept unchanged and the cutting speed was optimized in relation to material thickness. Based on the result of these preliminary analyses and the short timeframe Masonite 3.2 mm was chosen as a suitable material.

Thus the following parameters were important in driving the design: material properties, wind interaction, human body and gravity field. To allow all these different driving forces to be incorporated into the design model, the design workflow for the pavilion was broken into different parts (Fig 2 & 3):

- Design model for overall design and issues such as human movement, vision control etc.
- Overall solid model for wind analyses
- Detailed surface model for material analyses
- Detailed model for fabrication and physical prototyping

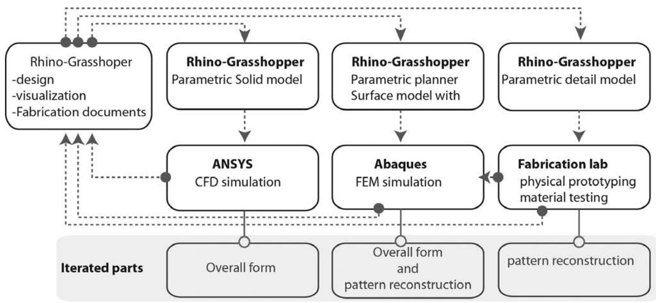

Fig. 2. 186-02, A diagram illustrating the design workflow for the pavilion was broken into different parts

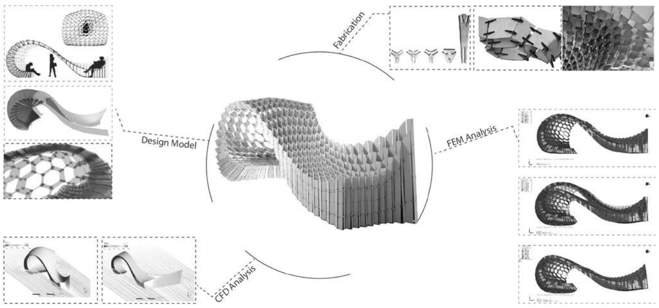

Fig. 3. 186-03, Illustration of the multifunctional pavilion physical prototype (in center) and the multi parameters driving forces involved in the design processes

What is structure and what is not structure?

Before the discussion about the results of the case study, a short description of the current attitude separating structure from material is needed. In our society we attempt to perceive materials and structure in different level. For example reinforced concrete is perceived as a structural material but a reinforced concrete column as a structure. However the online Cambridge dictionary, defines structure as the way in which the parts of a system or object are arranged or organised. Thus the notion of structure is not a thing, but a quality: it is the quality of being organised. This quality could be a natural property of the material and/or it could be arranged by human intervention using one or several materials.

Our attempt to understand material and structure at different levels returns to the notion of materiality and the way we construct material culture in society (Picon, 2010). In other words, it depends on the conceptual perspective or a theory of material culture that is socially constructed. That is why we attempt to perceive reinforced concrete as a structural material but a reinforced concrete column as a structure. Before industrialisation, man "lived in a world in which there was first of all no clear-cut demarcation line between the inorganic and the organic, or between a level of organisation characteristic of material and a more structural level… Materials are socially and culturally constructed at various levels" (Picon, 2010). Picon suggested that with the direction taken in digital design today "we are probably returning to a conception closer to pre-industrial with all the researchers on composites and smart materials and the tendency to solve more and more problems at the level of material design rather than structural design.

In the case study of multifunctional pavilion the challenge of structure and material was addressed by organizing the Masonite plates in hexagonal pattern, which as a whole took care of the dead load. Since the given material (Masonite) has poor compression and shear properties, nesting it in the hexagonal pattern improves these properties across the whole structure. Similar to a honeycomb shape structure in nature provides a structure with minimal density and achieves relatively high out-of-plane compression and shear properties.

Lesson learned from the multi-functional pavilion prototype

Form in formation

When designing the pavilion, at first glance it seemed that our interest in the mechanism of forces and their development was replacing the importance of construction (construction in the traditional sense) and building techniques. An object made from curves and surfaces was designed and the modulators (parameters) of that object were triggered by the forces assigned to them. The way in which form was determined had nothing to do with the traditional construction of brick components such as an arch, or composition of components into a certain geometrical form that produces an equilibrium state for the material composition. It seemed that the digital realization for the physical reality was directed towards the design of material composition in collaboration with the overall form. On closer inspection, one cannot fail to see that the forces do not construct the form or textures, they only form the constructed object. To understand this, we can ask what is the first element that these forces come into contact with? How is the form constructed digitally? How different is the construction of form in the digital and physical world in which the forces resulting from physical laws affect the steps taken in the construction of form?

Digital Surface as the precedent

In a physical experiment, we normally have a primary element such as a knitted surface, chain or anything which we can impose forces on, to make a form. Similarly, in the digital world, there are basic elements (such as a digital surface, solid etc.) that can be worked with. On the other hand, if I gave a person three different basic elements of, say, rope, clay and stone and asked that person to create one object from each of them, not only would the final products differ from each other, but also the process of designing them would have been very different. To construct a shape using rope, one can use weaving and hanging techniques, using clay one may use deformation and additive methods to create the object and using the stone one might use cutting and reduction in order to create the form. Though in CAD software one does not have the materiality in that sense, using curves to construct an object will affect the design process and, later, the final product.

In contemporary digital design practice in architecture, most of the time parametric and non-uniform rational basis spline (NURBS) modelling software is used for producing the important initial information about the building. Examples of this include Dongdaemun Design Plaza and Park (DDP), designed by Zaha Hadid Architects Ltd and Samoo Architects and Engineers. A Rhino software model was used as the main master model and as that model changed, the Computer Aided Three-dimensional Interactive Application (CATIA) model had to be rebuilt (Kwon et al., 2009). Software such as Rhino is commonly used by architecture schools and offices. In the digital world, elements, like NURBS curves, are analogous to the strings that are used to construct or assemble the surface in pgysical world. The non-material digital surface is defined by networks of NURBS curves or point clouds that are continuous.

NURBS (Non-Uniform Rational Basis Spline) is a mathematical model used in computer graphics for generating and representing curves and surfaces. It offers great flexibility and precision for handling both analytic (surfaces defined by common mathematical formulae) and modelled shapes. The NURBS surfaces are not only capable of overall deformation; they are also deformable within their texture. Changing the spacing in the V and U directions can change the number of grids, thus changing the density of the texture (Fig 4).

The case study of the multifunctional pavilion was a tool to explore the creation and negotiation of form and geometry of texture within a network of different driving forces. In this case, the Computational Fluid Dynamic (CFD) and Finite Element Method (FEM) models that were developed were looped as a cybernetic approach to the iteration of the overall form and geometry of texture. On the other hand, the feedback from the physical prototyping and fabrication was manually input into the FEM and geometric models. In such an approach, the level (overall form or texture or...) at which iteration occurs depends on the geometrical

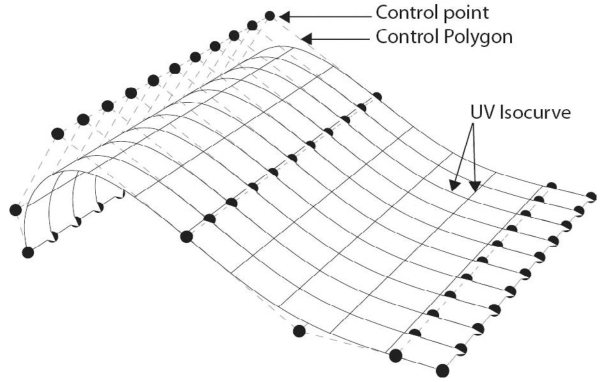

Fig. 4. 186-04, An illustration of NURBS surface and its inherent properties

parameters assigned to that part of the design stage. Hence the decisions made in the early design stages are of great importance (Fig 5). The overall geometry of the digital artefact produced is well adapted to the local climate conditions because its overall form is guided by feedback from CFD analyses. Similarly, the way in which the structure bends and twists has been improved by using feedback from structural analyses to help guide the overall form and density of texture. Thus the iteration occurs on the already constructed surface. The digital surfaces and their inherent properties are presented as an important working material in this process. The digital artefact developed still incorporates the morphology of the initial surface whilst driven by design parameters. When the development of the digital artefact is determined by the physical production, the fabrication constraints and limitations become design guidelines. Thus, the articulation and accentuation of the surface is highly influenced by the feedback from physical prototypes.

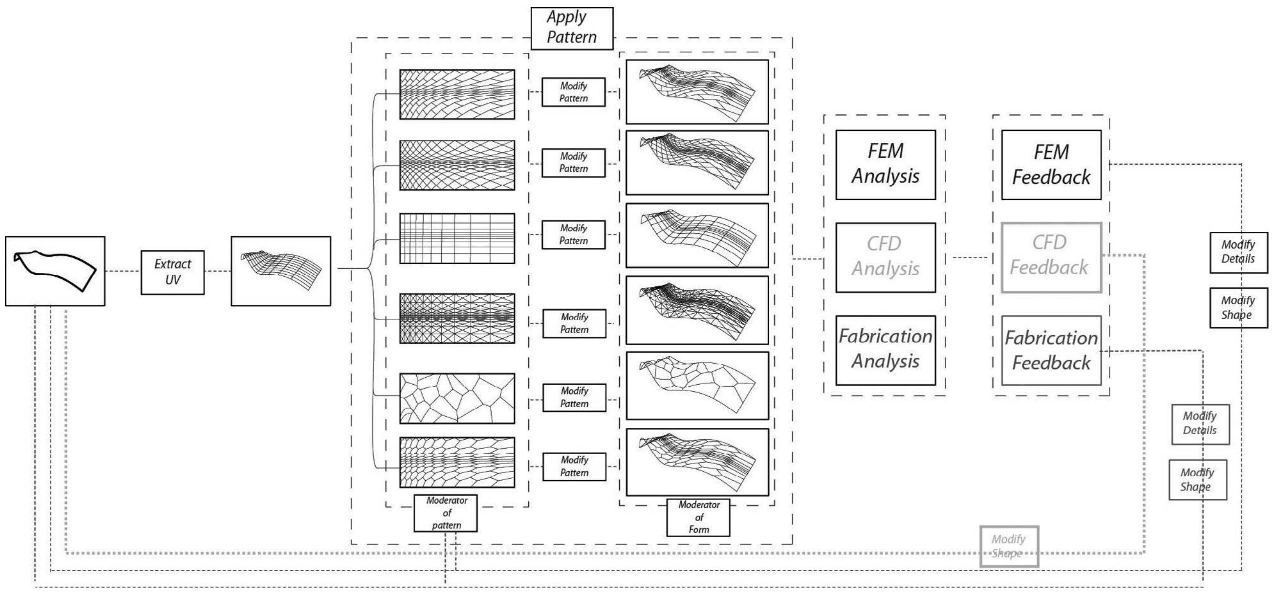

Fig. 5. 186-05, A diagram illustrating the process of iteration of the overall form and geometry of texture through driving forces in the multifunctional pavilion project.

Structuring the material

As the small components were designed, in order to distribute the dead load of the pavilion, we felt that the whole texture of the form was becoming structural. The opportunity to use FEM analysis software to calculate the equilibrium state in regard to material properties and to use a CNC machine to manufacture 1728 joints of different sizes and dimensions to handle the dead load meant a potential new load dispersal pattern. This new pattern was achieved, not through socially defined structural elements such as columns and beams, but through an understanding of the material, then a structuring of the material into a hexagonal pattern of components and finally an adjustment of the components' relationship to each other and their relationship to the whole form. When looking at the product, we could not identify an specific element as an structure, membrane and ornament. It seems that one emerge out of the other.

Conclusion

The seamless symbiosis between structural and non-structural elements of the multifunctional pavilion can be analysed as the result of the primacy of the surface and patterning within digital design processes. Thus, it is this primacy of the surface that the patterns applied to the digital surface have been forced to take a responsibility beyond the visual. Sometimes the pattern is articulated and accentuated to act as a structure and gradually becomes a membrane and returns to being a pattern again. The driving forces behind the structural and non-structural behaviour, shapes the constructed artefact at different levels (overall, componential etc.) depending on decisions made at the early design stage. Thus an influential factor in the formation process, does not construct the form and its inherent but triggers the elementary constructed artefact.

Digital technology, perhaps, enables production of structural parts that are understood to be not a separate entity from non-structural but an inherent part of it. In other word increasing the tension between representation and the performative aspects of the structure and non-structure. However, this interactive relationship between non-structural and structural parts, aesthetic and performative aspects, can reduce the typology of constituent parts of architecture. Thus risking the product towards an over-decorative and monotone architecture.

The seamless appearance of a product which is described as a highly mono-decorative and mono-ornamental can be analyse as the lack of systems correlation. One could say, that digital design processes in architecture has been applied to a single system rather than multiple systems. In the description of the multifunctional pavilion project, it has been shown that the system of components and surface that formed the design had the ability to change its use through formal transformation. By changing the density and thickness of the hexagonal system, the surface was forced to take structural responsibility. However, in practice, a project consists of multiple systems (such as a ventilation system, a structural system and a circulation system etc). Therefore, instead of a formal differentiation from a single system, we deal with differentiation within systems and cross-correlated differentiations between different systems of a project. We see this lack of systems cross-correlation as a problem that, if left unsolved, could pose a risk of total segregation between digital design practice and the rest of the disciplines involved in the production of buildings. More importantly, if the multi-system aspect of a project is not understood, the products of the digital design field may stay at the level of say, the facade, and be totally separated from the rest of a building's systems.

References

COOK, M. 2004. Digital Tectonics, Historical Perspective,ÄìFuture Prospects. *Digital tectonics. Great Britain: Wiley-Academy*, 40-49.

PICON, A. 2010. From Tectonic to Ornament: Towards a Different Materiality. *Digital culture in architecture.* Birkhaeuser.