

New tectonics: a preliminary framework involving classic and digital thinking

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The digital tectonic studies noticed the dramatic change of traditional architectural construction in association with digital technology. A more systematic framework of new tectonics combining digital and classic elements and processes is needed to explore the digital theory in the architecture field. The first step of this case-study research is to determine both the analytical factors of classic tectonics and the digital cases. The next step discusses emergent digital factors of tectonics. The third step applies the four new factors to the tectonic processes of five digital projects by well-known architects who have actual building experience in both predigital and digital works. Some phenomena of digital tectonics have emerged to reveal the dynamic factors of motion, information, generation and fabrication. In a preliminary framework of new tectonics, seven classic and four digital factors form a whole and interact with each other.

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The term *tectonics* originates from the Greek word *tekton*, which means carpenter or builder. It later evolved to include the meaning for *process of creation* referring to the creation of artistic works. This included the aspects of skill, method, material, and even concept. [Botticher \(1852\)](#) was the first to address the role of tectonics in architecture believing that there were two main elements: the nuclear inner structure and the outer cladding. The outer cladding should reflect the true nature of the internal nuclear. In addition to the concept of *nuclear* and *cladding*, he also introduced the idea of *part* and *whole*. Later, mainly inheriting [Laugier's \(1753\)](#) interpretation, [Semper \(1951\)](#) divided architecture into four elements based upon the method of construction: earthwork, hearth, framework and roof, and an enclosing membrane. Furthermore, he emphasized the 'joint' as the

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most fundamental factor of tectonics and suggested construction methods for various materials: wood and steel for the tectonics of the frame; and stone, earth, and concrete for the stereotomics of the earthwork (Semper, 1951).

Some researchers continued to propose observations based upon the classical theories of tectonics mentioned above. Sekler (1965) used examples to distinguish the relationship among structure, construction and tectonics. Vallhonrat (1988), following Sekler's lead, discussed the impact of tectonics on the techniques of structure and construction. Gregotti (1983) believed that detail is the description of the material and the principle of the structure. He used the works of Tadao Ando, Stephen Holl, and Mario Botta to illustrate that the method of construction could be a manifestation of architectural significance, and the structure was sometimes developed from the detailed description of the material itself. Similarly, Frascari (1983) pointed out that the significance of architecture came from the development of the structure. He was opposed to controlling details with technique and asserted that detail design is a way of innovative thinking and an exercise in the power of conscious judgment. Moreover, Frampton (1995), extending both his point of view of critical regionalism and Semper's theory, stated that the 'joint' in a structure is the most essential and smallest elemental unit. He furthermore defined tectonics as the poetics of construction (Frampton, 1990; Frampton, 1995).

1 Emergent digital tectonics

More recently, in order to address the digital process of design and construction, Mitchell (1998) was the first to argue that the fundamental elements and processes of classic digital construction are extremely different and even opposite. He proposed the idea of 'antitectonics' to expand the boundaries of classic design and constructional thinking for the digital age of architecture. Cache (2002) believed that Semper was pondering on the solutions available for the production of architecture because of the new industrial developments of that time. Nowadays, in the digital era, computers also provide the possibility for new methods of production and solutions. With the development and progress of technology, various new materials and production processes have become available to us; taking into consideration that information is also a kind of material (Cache, 2002). Furthermore, Spuybroek (2003) analyzed recent works of NOX using digital technology and proposed that the traditionally rigid process of tectonics has been reformed into something pliable. Leach (2004) examined the digital explorations of the UN Studio, FOA, dECOi, etc., and distinguished static *form* in

classic tectonics and dynamic *formation* in the emerging digital tectonics. In order to reevaluate the significance of tectonics in the digital design process, Gao (2004) analyzed many current examples of digital design in an effort to sort out some of the phenomena of digital tectonics.

The digital tectonic studies above, from different angles, noticed the dramatic change of traditional architectural construction in association with digital technology (Cache, 2002; Spuybroek, 2003; Leach, 2004; Gao, 2004). To theorize this dramatic change we all recognized at the end of the 20th century, we might begin by posing some questions: can or cannot the classic tectonic analysis be applied to digital designs that rely heavily on non-classic, digital technology in their design and construction processes? If yes, did any new factors evolve to be integrated into classic tectonics? If no, what kind of new theory of digital tectonics should we propose to substitute for the classic tectonic thinking that is so much part of the of history of architecture. In other words, a more systematic preliminary framework of new tectonics combining digital and/or classic elements and processes is needed to explore the digital theory in the architecture field. The objective of this paper is to evolve new factors and realizations, which are integrally tied to ‘digitality’, from the existing tectonic framework.

2 *Methodology and steps*

To initiate the current research, two issues must be addressed before tackling the case studies in order to obtain a more domain-general analysis. First, a larger choice of examples to be selected is critical because previous results, such as those of Cache (2002); Spuybroek (2003); Leach (2004); Cook (2004); and Gao (2004), are all specific works of new generation designers that are mostly architectural projects on paper only. Second, it is important to include digital examples from experienced designers such as Frank Gehry, Peter Eisenman, Zaha Hadid, Greg Lynn, etc., who have built many projects influenced by their traditional tectonic training, in order to compare and integrate the old and new factors.

Therefore, in this case-study research, three steps are proposed. The first step is to determine both the analytical factors of classic tectonics and the digital cases, in order to determine whether or not the classic factors are still appropriate for the tectonics of digital designs. In her paper, Gao (2004) summarized five classic factors: detail/joint, material, object, structure, and construction. The factors she drew from the classic theory of tectonics were more common ones, relevant to structural technique. However, other factors such as perception and topography, relevant

to the relationship between architecture and site as well as architecture and people, are also implied in classic tectonics (Frampton, 1995). In addition, topography is an essential factor in the construction of architecture. Thus, the seven classic factors used in this paper are joint, detail, material, object, structure, construction, and interaction. A definition of these factors is outlined in Section 3.

We chose the Far East International Digital Architectural Design Award (The FEIDAD Award) as the pool from which to select cases for our study (Liu, 2002a, 2003a, 2004). Since 2000, the FEIDAD Award is regarded as the largest digital competition. Each year, the award receives more than 100 projects from more than 40 countries. Five cases in this paper are chosen from projects that were given awards from 2000 to 2002:

- Case [1] Ambient Amplifiers (2000, Norway/USA)
- Case [2] DynaForm Cablecar Station (2000, Taiwan)
- Case [3] Aegis Hypo-Surface(c) Patent Pending (2001, France/UK)
- Case [4] BMW Frankfurt Motorshow Pavilion (2001, Germany)
- Case [5] Post Agriculture (2002, UK)

The next step of this research discusses emergent digital factors of tectonics, to see if some factors can be looked for in the analytical processes of the five cases in step one. They are then used to reexamine the same five cases in order to reveal the roles of any digital factors in tectonic thinking.

As mentioned in the beginning of this section, in the third step it will be necessary to apply any new factors, possibly found during the second step, to the tectonic processes of five digital projects by well-known architects who have actual building experience in both predigital and digital works. This validation of the new tectonic factors will be helpful in generalizing the preliminary framework of the new tectonics, which will be based primarily on case studies used as the methodology for this research. The five cases chosen here are all recipients of the FEIDAD Award and are from North America, Europe and Asia:

- Case [6] Hsinchu Museum of Digital Arts (Peter Eisenman/Yu-Tung Liu, USA/Taiwan)
- Case [7] Eyebeam Museum of Art and Technology (Greg Lynn, USA)
- Case [8] Subway Station IIDABASHI (Makoto Sei Waranabe, Japan)
- Case [9] AGORA Motion Space (OCEANnorth, Norway)

3 *Classic tectonic thinking*

3.1 *Discussion of the classic factors*

This study attempts to extend the digital tectonic phenomenon from classic tectonic observations. Therefore, we utilize the historical developments of tectonics (Botticher, 1852; Semper, 1951; Sekler, 1965; Gregotti, 1983; Frascari, 1983; Moneo, 1988; Vallhonrat, 1988; Frampton, 1995) to help explain the seven important tectonic factors when analyzing the digital cases. The definitions of the seven classic factors used in this research are as follows:

1. *Joint* is the most fundamental and smallest element of architectural construction. The joint can be regarded as the generator of construction. In various hierarchies, the joint links parts, and materials, and structures of the whole architecture (Semper, 1951; Frascari, 1983; Frampton, 1995).
2. *Detail* is the description of the material characteristics of architectural construction. It is also the formation of measurement, placing and making (Gregotti, 1983; Frascari, 1983).
3. *Material* is the element that represents the formation and composition of architectural construction (Semper, 1951; Moneo, 1988).
4. *Object* is the architectural part such as a column, wall, slab, door, window, etc. Many parts go into making the architectural whole (Botticher, 1852).
5. *Structure* is a concept, a unit or a process of transition of force. Structure is also a critical variable that influences tectonics (Sekler, 1965; Vallhonrat, 1988).
6. *Construction* is the operation of realizing the structural concept. Construction is also a hierarchical relational and logic process that places architectural objects in order from small to large (Sekler, 1965; Vallhonrat, 1988).
7. *Interaction* is the correspondence between site and architecture and between people and architecture, using the capacity of topography and perception (Frampton, 1995).

3.2 *Examination of the five cases*

3.2.1 *Case [1]*

This design is a rehearsal for a real-life case, The Toyen Park in Oslo and its surroundings. The intention is to investigate the use of computer

technology as an engine for mediation in a process where form and program reconfigure and redefine each other in a mutual time based process. The classic tectonic characteristics of this design are as follows.

3.2.1.1 Joint. In the design process of this project, the characteristics of the joint are vague. The development of the possible forms is investigated mainly by simulating the surface states of a given space. The development of the surface is derived from the study of the influence, which is produced by the conceptual environmental factors of the construction site. It appears that the layers in the space are lightly superimposed, instead of being jointed together. As shown in the sectional view in Figure 1a, the flowing surface shuttles in between the existing spaces. The surface's correlation with the original space is not clearly addressed;

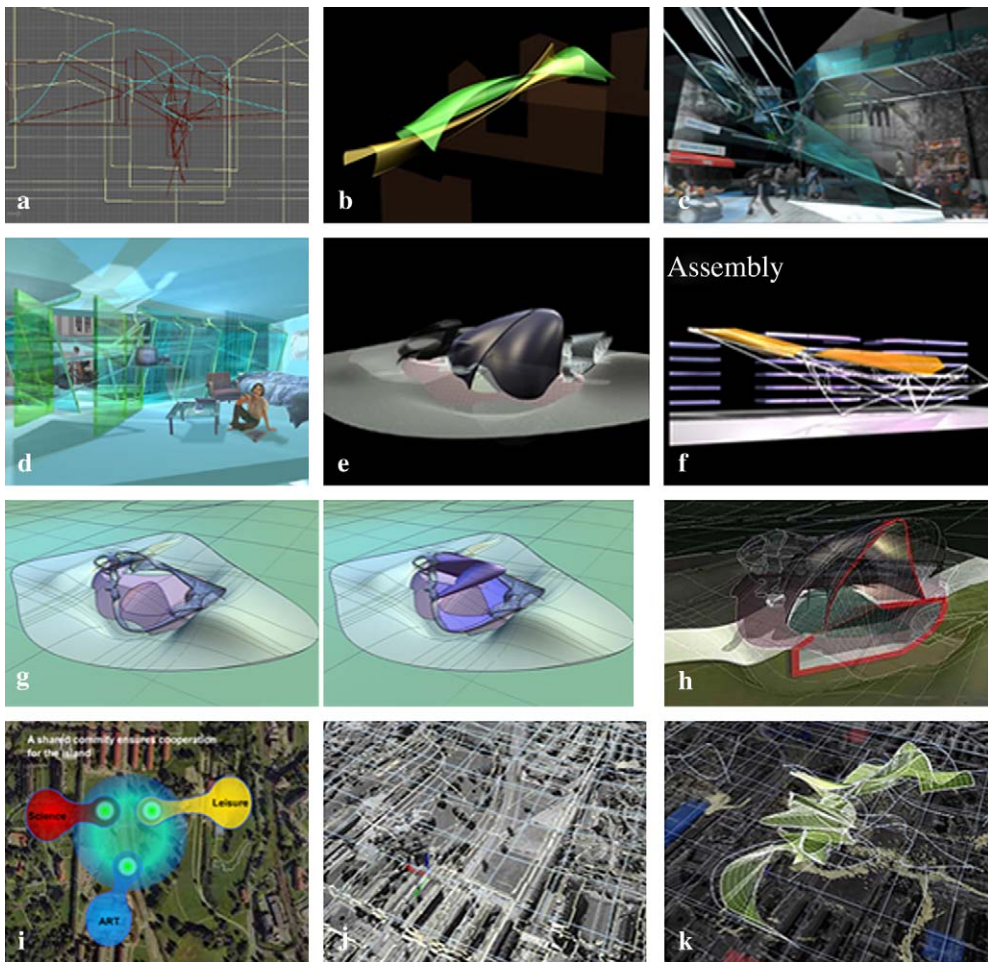


Figure 1 The classic analysis of Case 1, Ambient Amplifiers (Photos courtesy of Birger Sevaldson)

only that the surface is directly and lightly suspended in the existing spaces. The final presentation of the surface state is shown in [Figure 1b](#). The joint is not the smallest production element in this design form. The different surfaces defining the spaces interweave with each other and pierce through the original space. In this model, one can also observe how the surface of the skin layers under different states are put together; which still presents itself as being in a very abstract state. Through the transparent skin layer, the indistinct sub-surface can still be seen. The whole seems to be floating. Please note that there is no enough detailed description of the factors in the original documents of Case [1] provided by the designers. This paper, therefore, does not include any analysis of detail.

3.2.1.2 Material. In the perspective view the designer presents characteristics of some of the materials: an entire piece of glistening glass is given prominence. Both the transparency and the colors are greatly highlighted and employed throughout the perspective view. Furthermore, the spatial scene, which is similar to that of the steel frame or truss, is also observed, as seen in [Figure 1c](#) and [d](#).

3.2.1.3 Object. In [Figure 1e](#), the basic and generally understood architectural elements such as column, wall, beam, slab, door, window, etc. cannot be identified in any of the architecture. Instead, they are replaced by the spaces, which are defined and enclosed by the surfaces. It is very difficult to distinguish the spatial components. The tangible elements have lost their respective significance. The designer no longer considers that functionality and pattern should compliment each other, but, on the contrary, attempts to take into account the form of the space that can be enclosed and defined by the surface. The element, that was originally endowed with specific connotation, is substituted by more vague, environmental factors in order to re-model the pattern. Therefore, every surface generated by the environmental factors in this project could be considered to be the most basic element that can make up an integral space pattern. That is to say, the surface pattern has become the elemental unit that comprises the space.

3.2.1.4 Structure. In [Figure 1f](#), the designer employs a giant spatial truss within a spatial structure to link every activity taking place in the given space. With spatial structures for various activities brought together, the pedestrian who advances in the spatial truss can witness various interwoven activities, all of which are attached to a systematic framework. For the structure as a whole, the designer still places

emphasis on the relationship among the different levels of the architecture. In [Figure 1g](#), the location of the floor, foundation, framework, and nucleus and their corresponding relationships are revealed after the skin layer of the surface is peeled away in sequence.

3.2.1.5 Construction. [Figure 1h](#) shows the contour of the entire design form that was generated after performing structural analysis for the extended structure. There is no way for us to identify the kind of structure available in the real world that could make this form possible. Because of this uncertainty, this structure presents itself as a highly virtual structure. In the digital world, any structural design pattern is possible; however, we are seemingly observing the same artistic concepts that traditional tectonics tries to communicate. This project echoes the viewpoint that the structure and the presentation of a design form correspond with each other only because of the possibility of generating different kinds of spatial patterns by virtue of the freedom inherent in digital design.

3.2.1.6 Interaction. The initial form was laid upon the texture of the construction site. From [Figure 1h](#), one can observe that the deformation process of the form originates from some deformations that are related to the surface of the construction site. The architectural form is closely linked to the ambient environment. The relationship between the construction site and the form can be observed in [Figure 1i, j and k](#), which show a gradually rising 'island' evolving from the context of the existing construction site.

3.2.1.7 Summary. In Case [1], it is clear that some classic factors, such as material, structure, construction and interaction, still work very well to realize the design and latter construction processes. The stereotypic expressions of the joint and object factors are very vague. However, when we try to identify the most fundamental and smallest 'units' and 'linkages of units' represented in Case [1], we still find other kind of units and linkages involved such as digital images and generative motions. This evolving observation will be used to discuss digital tectonic factors in Section 4.

3.2.2 Case [2]

The environmental factors of this project were converted to the parameters that control the design pattern. By analyzing the dynamic shape, the context of urban environment and the relationship between the skin and the mass of the architecture is presented, leading to new possibilities for the planning of the surface, structure, section and space. The

characteristics of this design with respect to classic tectonic factors are as follows.

3.2.2.1 Joint. This design does not address the construction of the architecture from the viewpoint of the physical joint. Though the original physical joints are not clearly described in the design, we can observe from **Figure 2a** that the designer still employs a hierarchical concept of the joint from the hierarchical transformation of the mass, skin, floor, and structure. The indication of the joint in the level of the space is still very clear and definite in this respect. Owing to the dynamic evolution, the already-clear relationship between joints becomes vague as a result; however, a greater degree of freedom is also created.

3.2.2.2 Details. From **Figure 2b** one can observe that the form of the design is composed of different materials and formed by various structuring methods. The way of jointing various materials presents the pattern transformation of the architecture. Though the composition of the details is not particularly made clear in the entire design project, we can

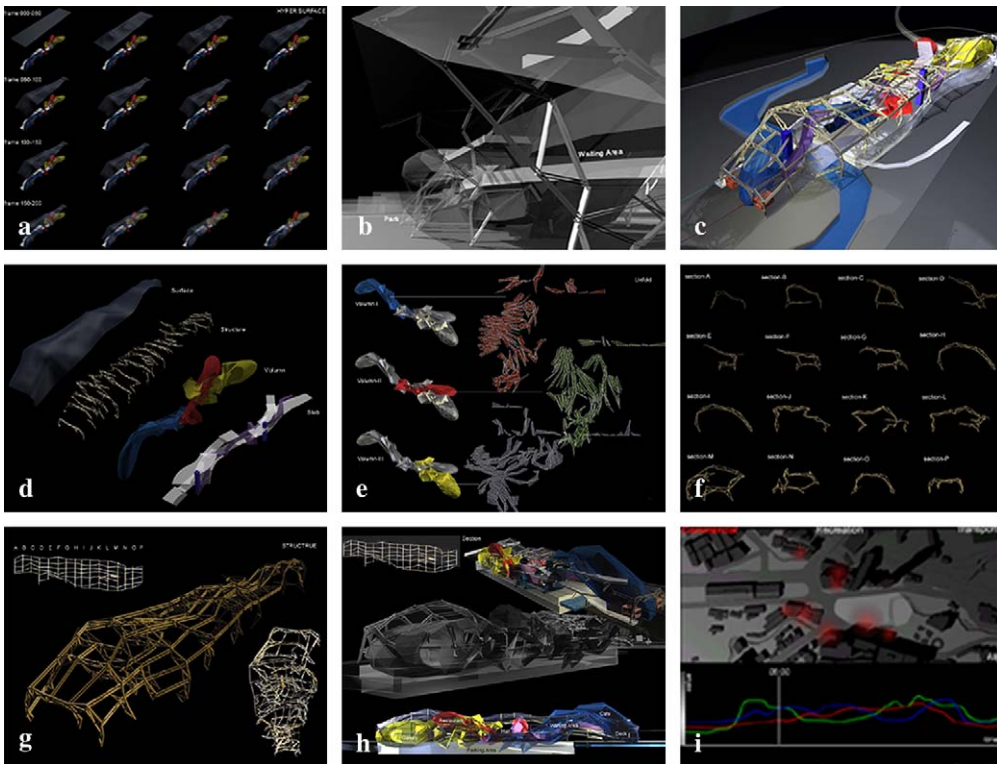


Figure 2 The classic analysis of Case 2, DynaForm Cablecar Station (Photos courtesy of Kuo-Chien Shen)

still observe that the designer takes into account the details of the architecture. [Figure 2b](#) shows the detailed relationship between the highly changeable forms of the frame system and the roof that is made of glass and is supported by the frame system.

3.2.2.3 Material. In [Figure 2c](#), where a digital model is presented, the designer employs computer rendering to present states of material such as transparency, metallic form, hazyness, color, etc. The viewer can make an analogy through the properties of the materials available in the real world. The tectonic factor of the material represents the feel and look of the material itself. The texture of the material is applied to bring out effects such as smoothness, glossiness and coarseness, which one can use to present the effects of the architecture's object while still in a digital environment; the actual feel and look of the material merely play a supporting role in the reference system.

3.2.2.4 Object. In this project, two aspects of the composition of the object are investigated. First, in the evolution process of its dynamic shape the designer goes further to manifest the four spatial systems: mass, skin, floor and structure — all four are formed as the dynamic shape evolves. [Figure 2c](#) addresses the manner in which the objects in these four spatial systems relate to the entire pattern. The four spatial systems eventually shape the complete structure of the architecture. Second, sub-objects also evolve under each spatial system. For instance, the definition of the structure was made after the mass, surface and floor were determined. In the perspective view we can see the entire structure co-defined by 16 sets of frames, while mass and surface and floor also have their respective sub-system.

3.2.2.5 Structure. The dynamic shape was structured through a clearly defined operating process and the evolution of the dynamic shape was defined by the environmental factor. The entire structure was, therefore, determined by such a design form; taking into consideration the relationship of the surface, framework, mass and the floor, and establishing the relationship among spatial structures from the outside in ([Figure 2d](#)). From the generation process of the 3-D model, we find that both skin and framework are major structures ([Figure 2e and f](#)).

3.2.2.6 Construction. In [Figure 2g and h](#) we can observe that the designer tries to use a framework to support the dynamic free form. With the assistance of a computer, the structural analysis for the dynamism of the free form can be performed easily. The framework system and the

surface to be structured can therefore be separated digitally. As a result, the generation of the digital model implies a new way of construction: be it a simple geometric structure or free form, everything can be modeled through a digital tectonic process, and have performed actual structural analysis and simulation with the assistance of a specialty computer software program.

3.2.2.7 Interaction. The design project attempts to handle, in the space, the complicated relationship of events that happen on a construction site (Figure 2i) and converts each part of the relationship into a form that can be brought to the space. With the correlation among different events being projected to the space, the project attempts to produce a close association and interaction between the environmental context and the structure's skin and mass; and between the shape and the sense of space.

3.2.2.8 Summary. Here, we find that this design is still strongly influenced in many ways by classic tectonics. Although digital thinking and construction are expressive in the designer's mind, this case could be analyzed perfectly by all ranges of classic factors from joint to interaction. However, the definitions of joint and interaction in this case have been gradually adjusted from a more stable assertion to a more dynamic representation. Furthermore, the traditional method of construction using linear and free-form geometry has been extended to a systematic process of digital generation.

3.2.3 Case [3]

This design presents a dynamic, wall-like art decoration, which can react to the actions and sounds of the surroundings. Through the operation of a sophisticated electronic device, the wall surface presents rich expressions and their variations, hence, making possible the intense interaction between the wall and the surrounding area. The characteristics of this design with respect to classic tectonic factors are as follows.

3.2.3.1 Joint. The unit element of this dynamic wall surface is an 8.0×8.0 m modular metal piece. The central joint-point links to a computer-controlled activation system, allowing the metal piece to adjust and turn in the desired direction (Figure 3a and b).

3.2.3.2 Details. The complete wall is composed of activators that are put together in a matrix-like arrangement. Each activator is linked to a computer in order to receive and transmit signals. Its unit device consists of a modular piece measuring 8.0×8.0 m. Having thousands of

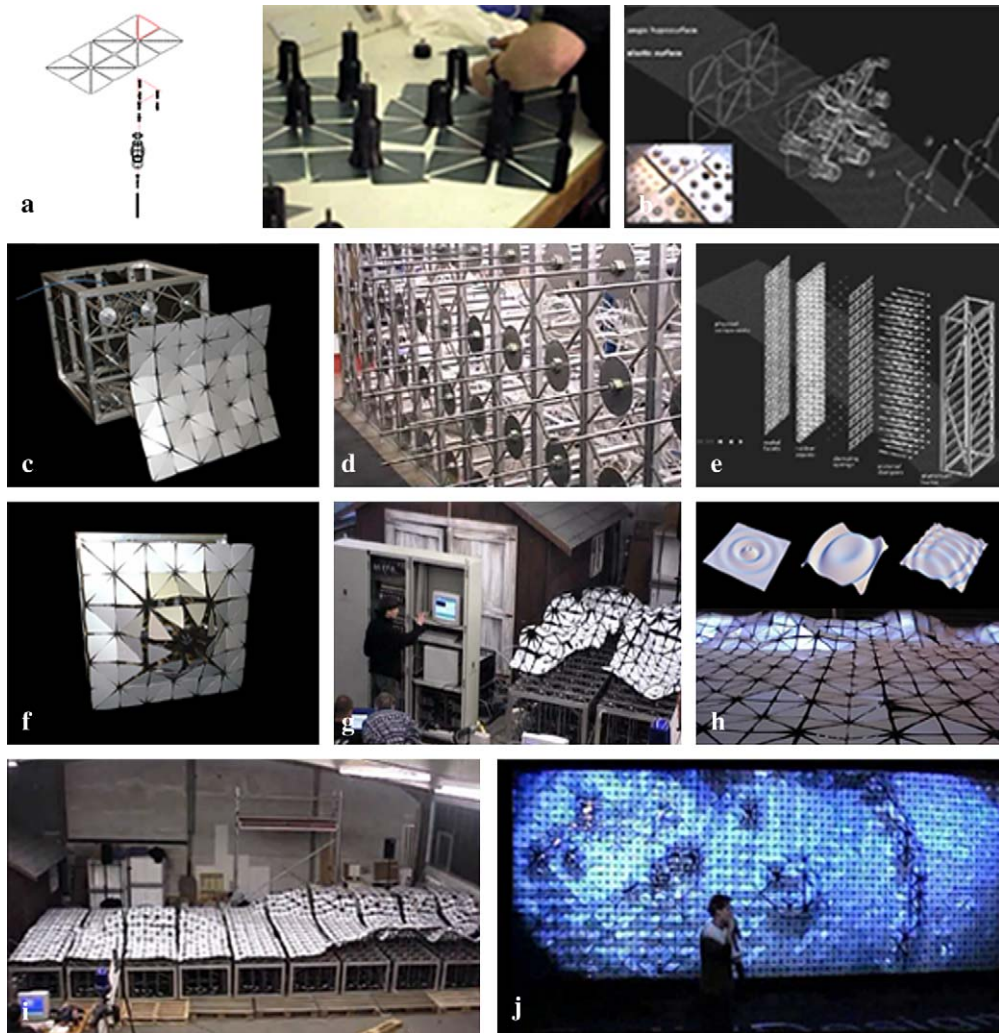


Figure 3 The classic analysis of Case 3, *Aegis Hypo-Surface*(c) Patent Pending (Photos courtesy of dECOi Architects)

activators, the structure presents itself as a screen with a 3-D effect. Figure 3c and d shows the construction of the detail joints of the activators and the connecting surface. This is a mechanical device whose surface is activated by a computer-controlled system.

3.2.3.3 Material. This work is actually a big mechanical device. It is controlled by a powerful computing system, which receives the sounds and actions from its surrounding. The major and substantial materials used are some machine equipment and metal pieces that enable the device's surface to have a dynamic effect. Because this design project is

a device that provides visual presentation, the overall presentation of the materials is manifested in the use of light in conjunction with the reflective metal pieces (Figure 3f and g).

3.2.3.4 Object. Figure 3e and f shows the unit object of the basic device that has an interactive surface. Each metal piece in the object is linked to a computer-controlled adjustment device. The entire metal device rumbles when in operation and presents a different picture, color and dynamic effect – as a response to the signals received from the surroundings. The device emphasizes not only the changeability of its surface, but also its ability to determine its presentation when responding to the activities taking place in the surroundings. The design offers a completely new way to explore the possibilities of spatial development because the sensitivity of the object becomes the key to the entire presentation as a result of the interaction.

3.2.3.5 Structure. The entire structure presents itself as a waveform as seen in mathematical models. As in these models, every wave fluctuation is transformed to a movable activator structure, allowing the pattern to change according to the reaction of the activator in correspondence to the signals received. The whole, therefore, becomes a sensitive system of form. Figure 3h shows the state presented as a result of the surface structure's geometric motion and pattern. Through the interaction of signals and forms, this kind of structuring method reflects how likely it is to directly transform the pattern to a substantial structure.

3.2.3.6 Construction. This project presents a reaction-sensitive digital device using a mechanical construction that combines an electronic sensor system, a computing system and a program algorithm, and finally links the whole to a physical mechanical construction (Figure 3i). The mechanical device continually receives signals from its surroundings during operation. The computer-controlled activator controls the rise and fall of the surface and hence the geometry, giving the rigid and cold machine a sense of beauty in its motion.

3.2.3.7 Interaction. Interactivity is most emphasized in this project. Through a dialogue with the environment a surface pattern can automatically present the state of the surface that best fits its environment. Figure 3j shows the continual images produced in response to the

rhythm, sound, and action coming from a musical performance. The wall and the performer jointly form an integral part of the whole stage, instead of merely serving as a background to the stage. The tectonics give weight to the assertion that the architecture should co-structure with the environment. This project changes the generally understood impression that the spatial pattern of architecture should be stable and steady. Since an intense interactivity with its environment exists, the wall itself can adequately manage a dynamic space. Though the device is only a part of what constitutes the wall, it somehow indicates the possibility of constructing an interactive architecture.

3.2.3.8 Summary. Similar to Case 2, all the classic tectonic factors work very well in the above analysis. However, it is very clear that these classic tectonic definitions should be broadened to subsume the digitality of this project. For the simpler factors, details, materials and objects of this design are composed of digital signal mechanisms, which can hardly be understood in a classic, analog way. For more procedural factors, the structure and construction include various and complex processes of computerized generation and fabrication in order to fulfill the whole architecture. Finally, the classic idea of interaction has been much more complicatedly extended to the idea of artifact–artificial interaction or so-called human–computer interaction.

3.2.4 Case [4]

This project describes a dynamic process whereby a car enters a site and in so doing transforms the design source of the major shape. The characteristics of this design with respect to classic tectonic factors are as follows.

3.2.4.1 Joint. This design has its origin in the simulation of kinetics and is applied to the motion of a car. As shown in [Figure 4a](#), the continuous animation reveals a shape that is derived from the interrupted interactive kinetic grids of the site after a car has passed through it. The whole process is a sequence of continual activities. This project directly copies the external pattern as the source for design consideration. However, here, the definition of the nature of the joint is expanded simultaneously. Though the joint no longer presents the detailed characteristics of the materials used in the construction, the presentation method of this key-frame still extends the meaning of the so-called ‘smallest narration unit’ that is connected to the joint. The joint, therefore, becomes the inevitable and smallest element in an effort to describe this dynamic shape. Please note that there is not enough description of the factor details in

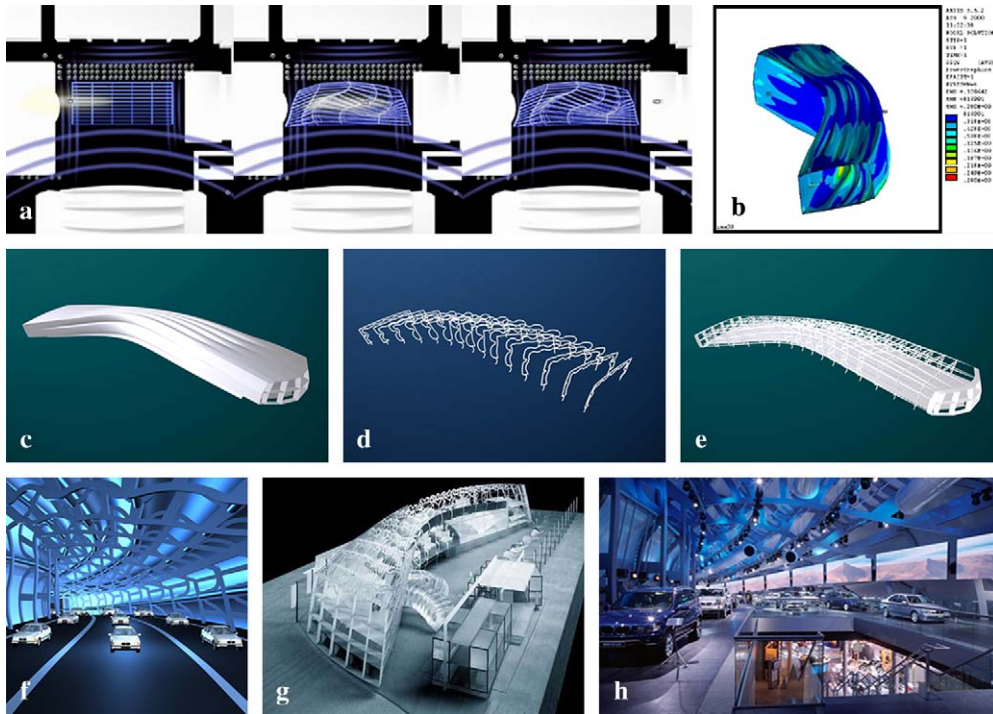


Figure 4 The classic analysis of Case 4, BMW Frankfurt Motorshow Pavilion (Photos courtesy of Bernhard Franken)

the original documents of Case [4] provided by the designers. This paper, therefore, does not include an analysis of the details.

3.2.4.2 Material. Figure 4b represents the energy distribution of the surface element, from which the transmitting and distribution of the force during construction of the surface are observed. The communication of the information becomes a part of the material presentation. The selection of the material to be used in the physical architecture loses its significance and the designer takes more into account on how to continually envelop the flowing surface. The true nature of the material itself is made weak and it is difficult to discover the material characteristics of the completed work through direct observation. The fluidity turns the feel and look inherent in the material into a more specialized effect. Even with the completed physical object of the architecture, the material maintains a unique virtual feel and look, making it a brand new material.

3.2.4.3 Object. As shown in Figure 4c, d and e, the generation of the architecture's object derives from the analysis of the shape. The supporting framework of the entire architectural body is structured by making sections in the section view and through the simulation at various

angles. All the spatial frameworks are linked together by a continuous, traversal, and horizontal structural system that finally completes the covering surface. This decomposition of a sequence of objects could not have been completed without a precise computing operation; one that calculates the distribution of the curvature and the composition of the forces. The curved pattern can be converted to valid operation procedures to be implemented during actual construction. The project reflects the digital design process, in which the analyses for the auxiliary structure and the object are performed using the computer medium. This helps when designing more complicated forms.

3.2.4.4 Structure. As shown in [Figure 4e](#), the construction of the structure is transformed from the initial design form by using the structure's supporting framework which is obtained from the digital operation of the geometry of the structure. The deflection force coming from the entire design form is added to the loads of the spatial framework in calculations. As shown in [Figure 4f](#), a hollow tube beam was employed to take the traverse lateral tension force in the entire structure in addition to the spatial framework as the main load-taking system. This kind of design clearly expresses a process of digital tectonics. It can control and analyze the form effectively and has more potential to realize the construction of a more complicated form through the power of the computer.

3.2.4.5 Construction. As shown in [Figure 4g](#), a single framework system was considered for the entire structure after the performance of a series of structural analyses. It is, however, not a vertical or horizontal static beam structure. Instead, the entire construction puts more emphases on dynamic forces. As shown in [Figure 4h](#), the complexity of the interior structure does not affect the design prototype of the initial whole form. The framework and the skin were clearly separated, which made the entire pattern simpler and more comprehensive.

3.2.4.6 Interaction. The internal function of this project is a car exhibition. It not only reflects the release of the dynamic energy from a moving vehicle in the form of a pattern, but its interior space also further appeals to the sensory experience. As shown in [Figure 4f](#), the design of the space uses the street as the spatial element and therefore the dynamic shape envelops the main streets surrounding it into an interior space. Through the turn of the form in the course of movement, the visitors can also sense the disturbing force from the space. Moreover, it also creates a different kind of sensory experience through the variation

of lights and the continual and extended playback on the screen. This design also portrays the spatial pattern in a more vigorous manner, allowing people to experience a different kind of space not commonly seen in our daily life.

3.2.4.7 Summary. In this case, the concepts of joints, materials, objects, structure, construction and interaction follow more closely their classic definitions as a regular built project. However, it would be still very difficult to go through the core of the design and construction processes if digital motion, generation and fabrication were not involved in the tectonic analysis.

3.2.5 Case [5]

This case's main theme reflects, in the spatial presentation of the architectural form, the special conditions captured in the construction site. The architecture, therefore, makes a breakthrough from being a static architectural 'object' and presents itself as an architectural 'being'; one that has a nervous system. The classic tectonic characteristics of this design are as follows.

3.2.5.1 Joint. The development of the entire structure is founded on a prototype consisting of multiple self-supporting air chambers. This pneumatic surface pattern prototype is the smallest unit element in the overall design. Meanwhile, all pneumatic surfaces are linked together by joints, forming a giant structural shape. As shown in [Figure 5a](#), the joint of the structure is designed as a dynamic link that varies with the changing environment. The joint can correspond to site-specific parameters, which are used as factors to generate the structure's pattern. Consequently, the entire structure changes whenever the structural joints change.

3.2.5.2 Details. As shown in [Figure 5b](#) and [c](#), the changes in the state of the pneumatic surface under a sequence of parameters are indicated in a series of studies using physical models. The structuring and surface form of the pneumatic unit can be presented in various states through the changes of parameters (such as orientation, deployment and density) and the applications of various strengths, depths and internal pressures to the joints of the structure.

3.2.5.3 Material. In a study that simulated the variations in the pneumatic surface, the membrane material feature was investigated. As shown in [Figure 5b](#) and [c](#), the variations of the pneumatic membrane's state under various conditions became the topic of the material study. In

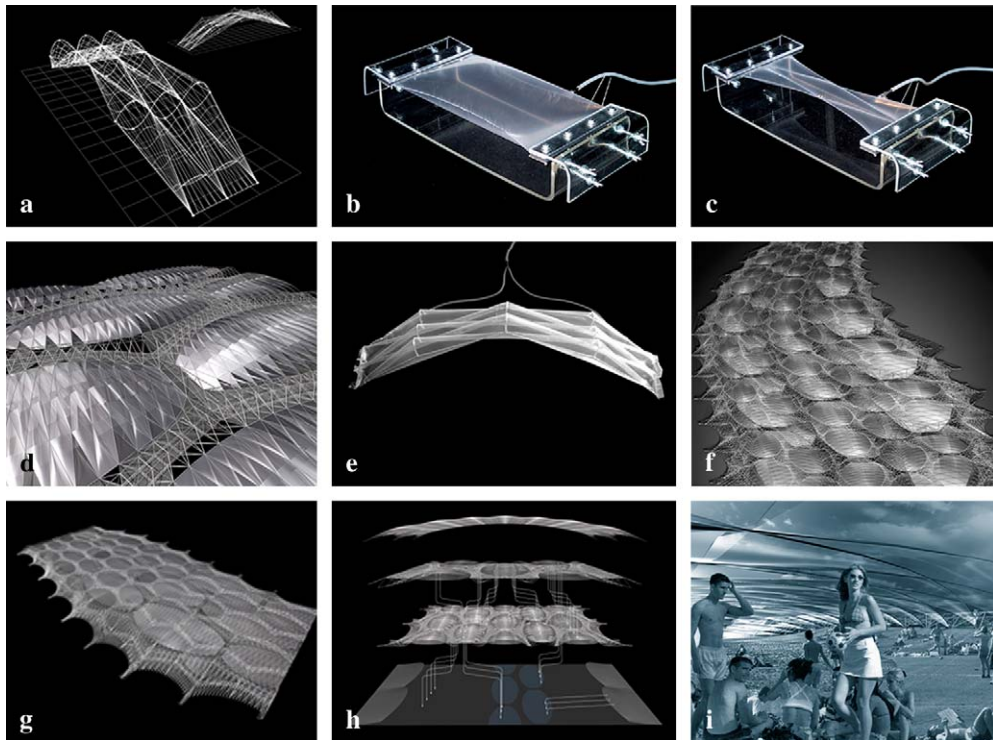


Figure 5 The classic analysis of Case 5, Post Agriculture (Photos courtesy of Achim Menges)

addition to the study of the surface of the pneumatic membrane, quite a few applications of the metallic truss were also observed in the perspective images of the design. The processing of digital images was performed in an attempt to give a more realistic feel and look of the material. Figure 5d illustrates the overall state of the material and the design form that the designer tried to communicate via digital images. From these figures, the method in which the pneumatic prototype and metallic truss are joined together can be discerned. Meanwhile, the material characteristics such as membrane transparency and metal reflectivity can also be expressed.

3.2.5.4 Object. Each pneumatic unit becomes the most basic design prototype. From Figure 5e we see the original object developed from the repeating process for the digital and physical objects. The process begins with the framework employed during the simulation of the pneumatic composition in the digital environment, and then proceeds to the study of the physical model; and finally returns to the study of the digital environmental state when a large quantity of the pneumatic prototypes

are employed. Therefore, the development of the pneumatic prototype object becomes the key to the construction of the overall design form. It also emphasizes the fact that such an object has the ability to interact with the surrounding environment at various levels of its structure, and to reflect the characteristics of different states of the environment and thereby achieve different presentations.

3.2.5.5 Structure. The design emphasizes an organized model that is generated from the behavior of the structure at a deeper level, indicating a dynamic relationship between the specific external conditions and the internal structural system. Such a relationship is mentioned above. This begins with the study of a pneumatic unit, which proceeded to the formation of a pneumatic object, and finally forms a structural pattern with a big stretch. A different spatial object was developed from the pneumatic prototype that could develop an intensive association with the environmental conditions of the construction site. When this giant structural system was formed the highly changeable and dynamic spatial planning was at the same time defined. From [Figure 5f](#) and [g](#), it is clear that the entire structure was established on the different levels of the structural system's functions. This enables the structural pattern of the giant system to change under different environmental conditions.

3.2.5.6 Construction. Conceptually, this project employs many viewpoints of an algorithm. It attempts to achieve a required self-conscious framework and organization, and hopes the architecture will react, accept planning, and accommodate the need for change, which ensue from changes in the space and environment. This also enables the entire construction to be established on the changing logic. For instance, one can construct a highly changeable space for the pneumatic's structure from the result of geometric procedures and the application of pre-stressing force on the membrane. Such a procedure and application of pre-stressing results from defining and arranging the boundary and joints, and from changing the parameters and volume of the pneumatic by using compressed air. [Figure 5h](#) shows a sketch of the cross-section of the decomposed construction, bringing out the correlation among the structure's various levels and the connection of the pneumatic surface.

3.2.5.7 Interaction. As shown in [Figure 5i](#), the presentation of the final design form is the result of a series of framework processes and the manipulation of the physical material. Confined to the restrictions imposed by an organization's logic and structure's system, these

operations enable the structure's joint design to correspond to site-specific parameters as a response to the change in the environment requirement. The entire pattern also changes with the changing state. Likewise, the designer also utilizes the sophisticated computerized perspective view to present the variations in the state of the environment. Through the assistance of the digital medium, it is easy for a 3-D model to present various design possibilities. This helps the thinking process and the presentation of the design. The design finally presents a spatial form with a big stretch, which can offer a place able to provide agreeable light and temperature according to different spatial planning, decorated for different activities.

3.2.5.8 Summary. This case, without any doubt, is easily recognizable by its classic tectonic factors because the pneumatic was also a typical material and structural composition of the 20th century. Nevertheless, the dynamic interaction between the building formation (joints, objects and structure) and site condition is far more complex than the classic tectonic definition.

4 Digital tectonic thinking

4.1 Emergence of the digital phenomena and factors

Since the 1990s, a wide range of digital technology has been utilized as part of a new medium that aids the design process. The many characteristics of the digital environment such as the dynamic manipulating process, immateriality, and zero gravity state, are gradually changing the design and construction processes/methods of architecture. Multi-dimensional as well as digital technology such as 3-D modeling software, generative systems/algorithms and CAD/CAM fabrication are also contributing to the changes. The digital procedures underlying the design and construction processes differ from the traditional ways of architectural thinking (Mitchell, 1998; Kolarevic, 2000; Kloft, 2001; Ruby, 2001; Liu, 2001; De Luca and Nardini, 2002; Ham, 2003). On the one hand, based on the analysis of the above five digital cases, using the seven classic factors, we find that the concept of classic tectonics is still appropriate for digital design although some parts of the definitions of the analytical factors should be further adjusted and extended. On the other hand, some of the critical phenomena of tectonic thinking involved in the five digital cases are far beyond the boundary of classic tectonics; the classic factors are no longer sufficient. Therefore, another set of digital tectonic factors is necessary to coexist with classic tectonics. This new set of digital tectonic factors will reflect the reality of current tectonic considerations in digital

architecture, which have evolved from the architecture of the 20th century.

Digital phenomena involved in the five above-mentioned cases include the following new characteristics. First, digital projects use the dynamic process to deduce the design concept, such as animation and morphing during the processes of form making or even form evolution. Second, immateriality in the digital and virtual environment derives from the concept of material by merging the units of digital information into the building form, and function as a kind of new material. Information, therefore, becomes a new kind of building surface material. Third, computer software such as generative systems/algorithms is used to assist the form-evolving process in the early stages of design. Designers input some parameters and operate the generative system/algorithm to automatically produce various design forms, which are then chosen by the designers to suit their requirements. Finally, a new design process then emerges before the construction stage. Designers utilize the CAD/CAM fabrication technology such as rapid-prototyping (RP), computer numeric control (CNC), and 3-D scanning to explore new methods of assembly. It includes the accurate processes of producing, fabrication, testing and assembling the digital design components for both linear and free-form geometries.

Based on the four phenomena that emerged from the digital elaboration of the cases presented here, four new factors can be considered for the first time for further analysis. The definitions of the digital factors are as follows:

1. *Motion* is the serial process of dynamic operation in the manipulation of design concepts and form evolution.
2. *Information* is the utilization of digital signals in any form on the skin or surface of a building as a newly appearing material.
3. *Generation* is the automatic generating process of form or concept by the application of software generative systems/algorithms.
4. *Fabrication* is the process of fabricating the design components and the method of construction with the aid of CAD/CAM technology.

4.2 *Re-examination of the five cases*

4.2.1 *Case [1]*

In the design process of this project, environmental factors were entered into the computer generative program. The change to the form, as a result of these entered factors, was then investigated. Key-frame was used

as a reference base to interactively define both form and space. The characteristics of this design with respect to digital tectonic factors are as follows.

4.2.1.1 Motion. In the design pattern of this conceptual ‘island’, the modeling of a shape is performed by operating a multi-clustered skeleton animation. This uses the environmental factors of the site and the designer’s intentions as the driving force for dynamic deformation. The animation simulates the ambient textural events around the site, and converts them to the events’ relationship with a territory of stance, and begins to produce a dynamic change in the form. As shown in Figure 6a, the generation of the ‘island’ form is completed by the following process: after performing a series of dynamic deformations, the designer determines the skeleton frame, which is used as the major framework for the surface

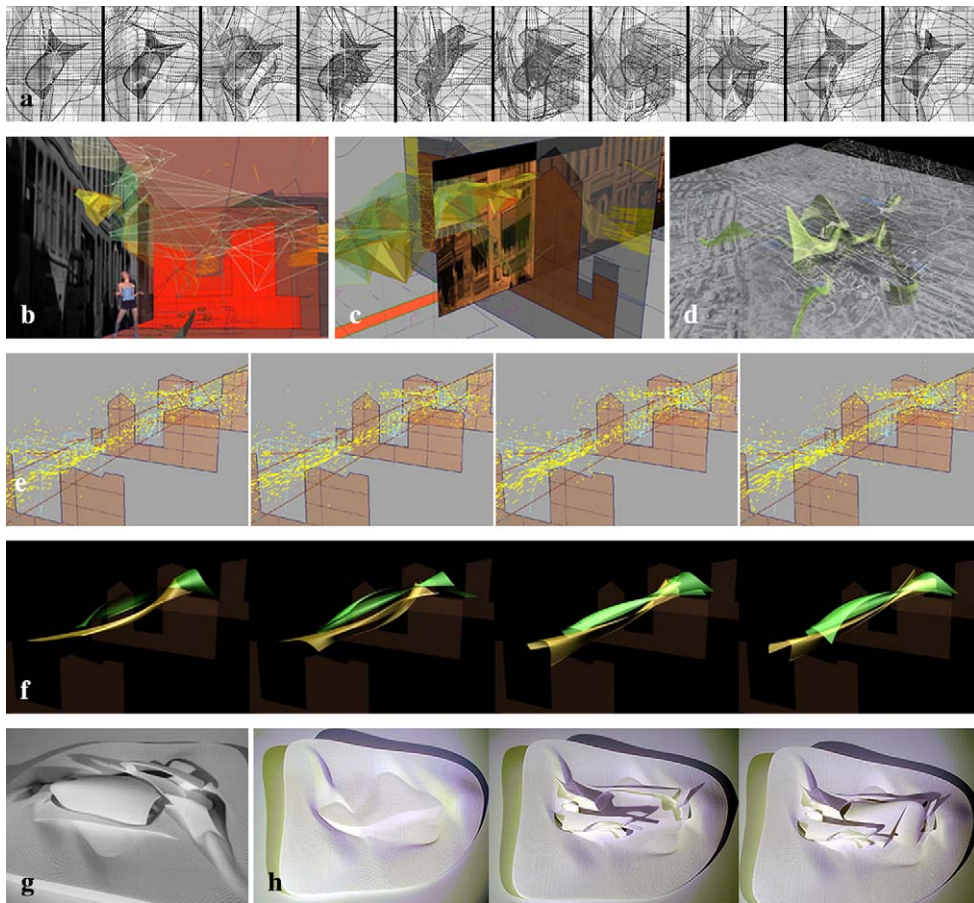


Figure 6 The digital analysis of Case 1, Ambient Amplifiers (Photos courtesy of Birger Sevaldson)

of the design for the 'island' form in the next step. The conditions of the site are used as references for the deformation of the design form so that a conceptual design form that corresponds to the site can be obtained.

4.2.1.2 Information. Note that the mapping of the image has become a way of presenting material. In [Figure 6b](#), the view of a street is a merging of the image and the design space, employing the arrangement of both the back and front spaces and the transparent pasted images of various depths. Moreover, the use of a large quantity of mapping images enabled the designer to easily present the desired sense of space by presenting from a perspective view. As shown in [Figure 6c](#), the presentation of the image is emphasized with interwoven images and diagrams. By superimposing transparency, the penetrability of the space is presented. A highly colorful visual presentation is employed in an attempt to produce a vivid and rich space. Because the operation is performed in a digital environment, the visual effect plays a comparatively more important role. Hence, the material's properties are replaced by the information images in order to compensate for the lack of feel and look in the material.

4.2.1.3 Generation. In the street scaffold of this project, the modeling of the design form is investigated using particle animation with the possible activity modes in the environment and the arena relationship of the space as variable parameters. In the space's sequential key-frame (shown in [Figure 6e](#)), the designer expresses the state between the peripheral service route and a hard pavement system. This is done in an attempt to describe the route for pedestrians and the possible vaguely developed states between the surfaces of games and leisure activities. What is presented here represents the result of development, with time, of the various territories of activities interwoven in an environment. The animation simulates how the ambient textural events around the site are converted to the relationship within the territory of a force field hence generating a series of space-time transitional images. And finally, from these images, the relationship between the design form and the spatial organization for the street scaffold was hence obtained and then converted to the pattern of a framework that might be developed in the structure ([Figure 6f](#)). In addition, as shown in [Figure 6d](#), we can observe this process as it shows the interweaving of different modes of representation and the derivation of a generative diagrammatic shape.

4.2.1.4 Fabrication. In order to explore the possible structures for the design form, CAD/CAM technology was employed during the design process to fabricate precise models. [Figure 6g](#) shows the physical model achieved by a Rapid Prototyping machine using the data output from

the computer models. Figure 6h shows the models that present the relationship of structures at various levels. This enables the designer to easily grasp the spatial organization of the design form and overall construction, as well as to analyze its rationality.

4.2.2 Case [2]

The complex activities and events in the site, field branch and dynamic paths, were analyzed and made as environmental factors that could be used as parameters. These factors became reference points in the manipulation of the form development. Through a deeper study of the environmental factors, the Dynaform extended from the activities of a human being on the site and enabled the interior and exterior spaces of the architecture to more closely integrate with the urban context. The characteristics of this design with respect to digital tectonic factors are as follows.

4.2.2.1 Motion. The analysis for activity density around the site during a 24 h period is shown in Figure 7a. These data were employed as configuration parameters during the design of a dynamic simulation. The paths that were generated as a result of these activities

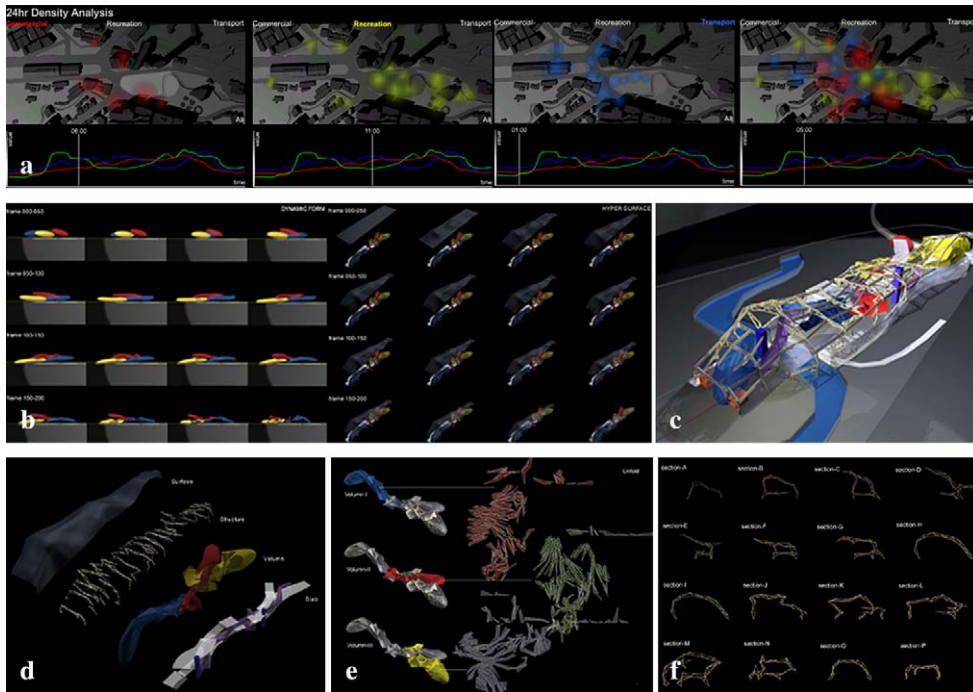


Figure 7 The digital analysis of Case 2, DynaForm Cablecar Station (Photos courtesy of Kuo-Chien Shen)

communicated the implied texture of the site environment through a connection with the activities and events. The texture was then converted to force, field and path, all of which were used as references in the design of the parameters. The design form was modeled after the dynamic animation was performed, based on the environmental factors of the site. Please note that there is not enough description for the factor information in the original documents of Case [2] provided by the designers. This paper, therefore, does not include the analysis of information.

4.2.2.2 Generation. The factor of environmental activity became the condition that controlled the parameters of the design formula. The activity intensities of the events around the environment are composed of values from the parameters for a series of generative formulas in a computer system. Through the adjustment of the system's parameters, the state of the design form was controlled. In the description, for the definition of the designer's formula, small parameter values correspond to stable behaviors. When the value increases, the behavior of the system becomes more complicated, even to a degree of chaos. The range of the parameter values maintains the balance of the Dynaform. Therefore, the configuration of the parameter becomes the reference point for the deformation of the design form, and the look of the final form is determined by a series of deformation processes. Furthermore, the path of the motion also becomes the guiding parameter, determining the orientation, force and motion intensity of the form. As shown in [Figure 7b](#), the form develops close relationships at the skin, structural framework, mass, and floor levels through dynamic generation use of the parameters. As shown in [Figure 7c](#) the look of the final Dynaform was determined after a series of evolutions of the parameter-controlled pattern. The relationship of the pattern is no longer a presentation of the internal faculty while the parameter system converted from environmental events becomes the key information that controls the form. Through the control of the parameter, the generation of the form presents itself in a state of uncertainty. The interactive forces among the masses generate a new pattern for each space interacting with another. This kind of practice enables a stronger connection between interior and exterior spaces and the generation of a dramatic space.

4.2.2.3 Fabrication. From [Figure 7d](#) we can clearly see that the designer divided the design form into four major structural systems: skin, structural framework, mass, and floor. These structures were further divided into smaller objects. For example, the skin was divided into

a myriad of fine object units that could be assembled together; the entire pattern, through the cross-section view, was found to be divided into framework units and objects that could be reasonably built (Figure 7e and f). Though the sectioned and designed components were not fabricated during the design process, these operation processes indicate that the designers had started to ponder on the fabrication methods of the architecture.

4.2.3 Case [3]

Case three is a dynamic wall-like device that uses a computer to simulate the effects of sounds and actions coming from a given environment. It converts them to the input and output signals during a computer-controlled operation and changes the color and the surface pattern according to the force acting on it. Finally, through the mechanical structure, it presents the mathematic waveform simulated by the computer's output signals. The characteristics of this design with respect to digital tectonic factors are as follows.

4.2.3.1 Motion. This design concept is to build a wall that can interact with the environment and a surface pattern that can respond to the motions and sounds of the environment by producing different kinds of movement on its surface. The variation of the surface was at first simulated by a computer. From the digital image of the mathematic wave fluctuation, the possible variations of the surface's pattern were then investigated in order to simulate the relationship that reflects a series of variations of a surface waveform. Figure 8a is a diagram that shows the variations of a waveform and the concept of the activator's operation behind the scenes.

4.2.3.2 Information. This work itself is actually a big mechanical device. The equipment used in this system, as shown in Figure 8b, is controlled by a powerful computing system, which receives the sounds and actions from the surrounding environment. The actual feel and look of the material is not emphasized in this design project while the communication of the information carried on the signals generated by the electronic system replaces the presentation of the material. These signals are converted to the force that drives the activator and enables it to work. The signals sent out from each set of objects must be transformed into different systems. For example, the graphical image in the computer is transformed to a mathematical matrix; then from the matrix to the intensity of the electronic signals; then to the feedback for the machine.

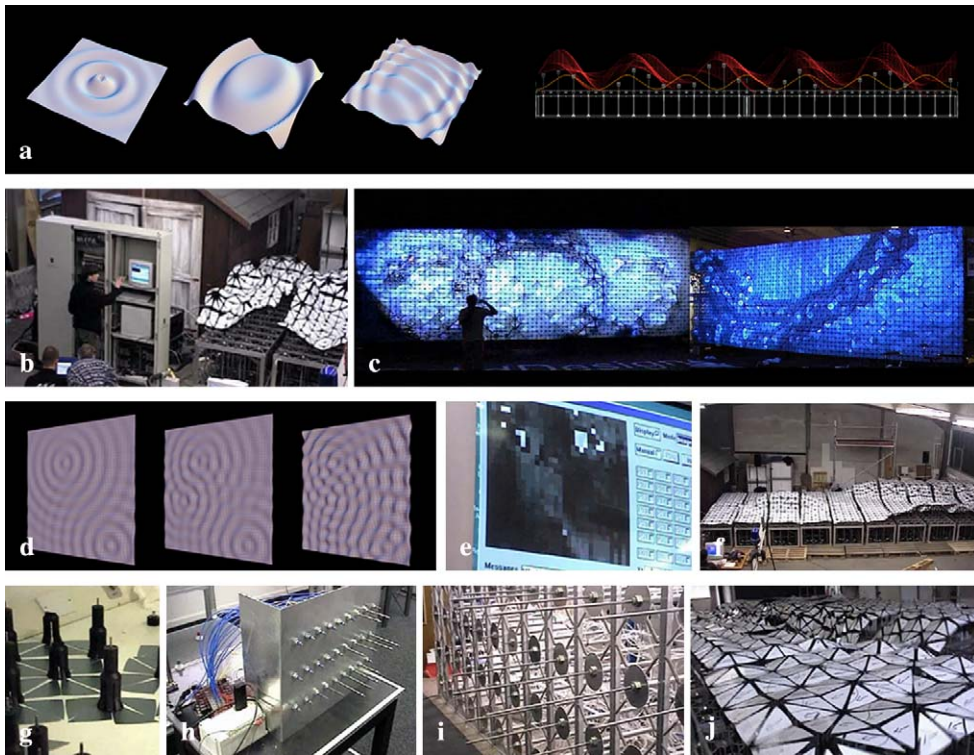


Figure 8 The digital analysis of Case 3, Aegis Hypo-Surface(c) Patent Pending (Photos courtesy of dECOi Architects)

Finally, the surface activator receives a given feedback and reacts accordingly. These sequential transformations need to connect to various operational modes; therefore, the transformation of these signals also displays the effect of the informational material. Moreover, the entire work was mostly put under the digital control of a computer, which can be seen in Figure 8c. The presentation of the physical material is replaced by the digitally controlled signals.

4.2.3.3 Generation. Computer graphics were employed to simulate the variations of the waveform sequences at different times. As seen in Figure 8d, the computer simulated the wave variations of these surface patterns, which were determined based upon the signals received from the environment. The color and picture of the surface pattern were changed according to the signals' force acting on the device. These waveform transformations were converted to data in a matrix that can be controlled and operated by a computer, enabling the computer to recognize the change of pattern that was to be delivered when a different input signal was received (Figure 8e). Afterwards, these digital data correlated

with a physical mechanical device, which would require the combination and adjustments to many technologies to realize in the real world, produced the pattern variations shown in the digital environment (Figure 8f). The final presentation of the pattern variation was generated by the continual input of different information from the surrounding environment.

4.2.3.4 Fabrication. Six design prototypes, from small to large, were made in this design project. Each object was fabricated separately and then assembled with the others. Each was also tested and its design modified during the fabrication process. From Figure 8g to j, we can see clearly the process of the design and the fabrication of the device, from the smallest object, which failed to show flexibility in the dynamic test. After repeated tests, assemblies, and modifications to the hardware object and software program, the designer was able to develop a large piece of a wall-like device that could freely present a surface that produces a natural wave-like form. As for this digitally controlled device, all objects must be assembled and integrated under strict conditions. There are on-going tests and modifications in this kind of fabrication process.

4.2.4 Case [4]

This project uses the momentum of a car running into the field of site as the conceptual pattern for the design form, and then converts the obtained form to the framework of the architecture. The digital tectonic characteristics of this design are as follows.

4.2.4.1 Motion. This project attempts to obtain the design form from the interaction taking place between the kinetic energy of a running car and the matrix of the force field on the site. As shown in Figure 9a below, the energy released is recorded one by one when a car runs through the site. Field base lines that have a relationship with the site are used to model a major design form prototype with the help of animated simulation. This dynamically simulated form is named by the designer Master Geometry, and is in compliance with the Doppler Effect.

4.2.4.2 Information. The street is used as the site for the presentation of a major concept and image within the architecture. In this form there is a geometric framework that goes through dramatic changes. The main purpose is to present, through the real, physical structure, the special spatial form and the force formed as a result of the acceleration and dynamic tension in the virtual space. It allows the spectator to receive from the

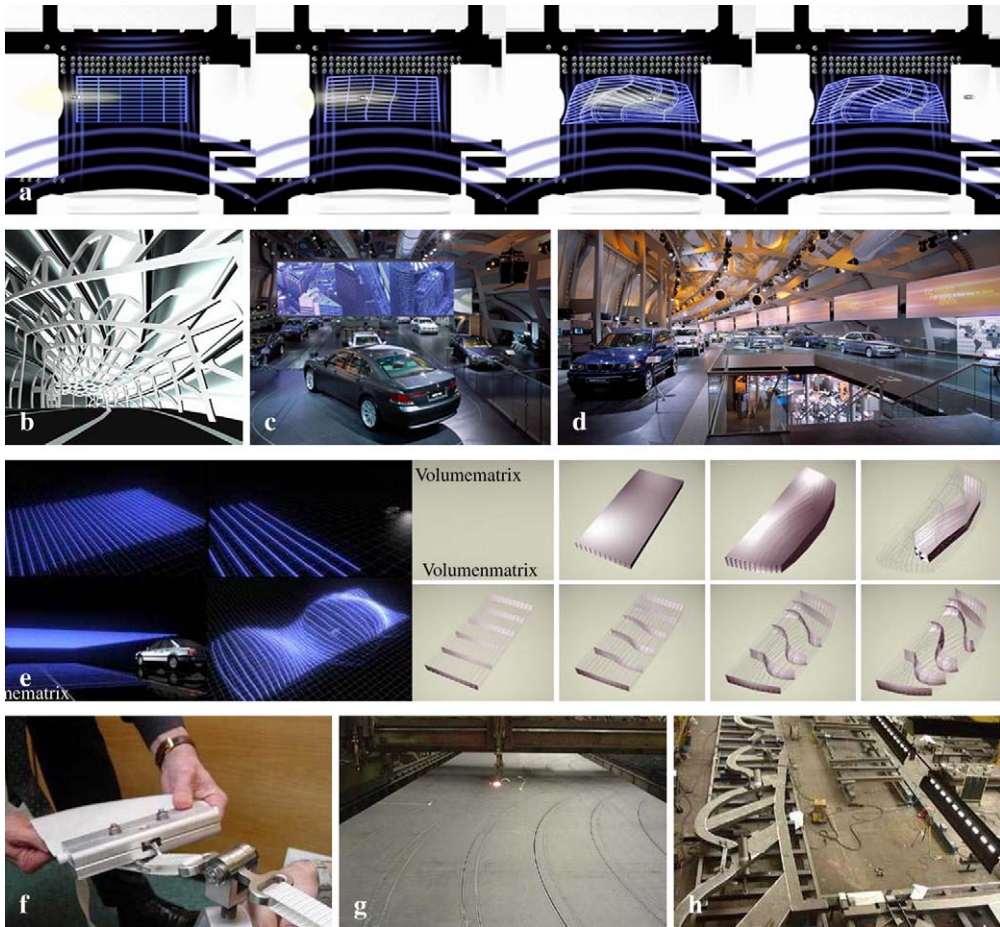


Figure 9 The digital analysis of Case 4, BMW Frankfurt Motorshow Pavilion (Photos courtesy of Achim Menges)

space of the framework the message of speed, which it purposes to present. The information of the ‘speed space’, which a digital space may present, is brought to the spectator conceptually as a spatial presentation.

4.2.4.3 Generation. This work attempts to display a new showroom concept through a design method that uses parameters. It asserts that the Dynaform is generated as a result of the acceleration, dynamics and tension in the space. The form variation in the design concept is acquired mainly from simulating changes in the mechanical system, using a computer. The existing tube matrix is affected by the simulation through dynamic mechanics and physical change, and by giving change to the acceleration parameter. The acceleration contributes to disturbing the air flow, and hence makes the tube matrix deform.

Therefore, the acceleration becomes the basic parameter for the spatial form. All through the process, a computer is used to simulate all the information and force, in order to generate a form through the interaction between the geometric framework and the acceleration (Figure 9e).

4.2.4.4 Fabrication. Continuing from the initial major design form developed from the concept, the next design process proceeds using the initial form as a reference – regardless of whether it is for structural analysis or computer simulation. Both the structure and construction method related to the design were converted from the initial major form. As shown in Figure 9e, with the aid of the computer medium the designer can perform a simulation of the structure directly on the initial form, including making a cross-section projection of the framework's profile, and the disassembling and assembling of objects. Through experiments on the digitally designed structure, the prototype was adjusted to a more appropriate presentation for the pattern and was made compliant with the structure's logics. Figure 9f, g and h shows the design elements that were generated using the output data from the digital models of the structure's objects. These were formed with the help of CAD/CAM technology. The rationality of the design construction was discussed. The objects and forms were then fabricated by the factory and assembled at the site.

4.2.5 Case [5]

The design process in this case was established on a clearly defined structural development. The changes of the conditions under various states enabled the presentation of the structure, and were implemented, as feedback, to the spatial pattern of the entire structure. The project attempts to develop a strategy that can include and respond to data. Such a strategy can also provide in the design process planning procedures that have highly integrated and changeable modes and vitality. The digital tectonic characteristics of this design are as follows.

4.2.5.1 Motion. From the land's density distribution analysis diagram as shown in Figure 10a, is described the environment's dynamic density variation and the distributed area. With dynamic and digital graphic analysis presented, the variation of values of the regional and national agriculture produce and population is clearly shown, allowing the designer to make obvious the concept to be presented. The dynamic

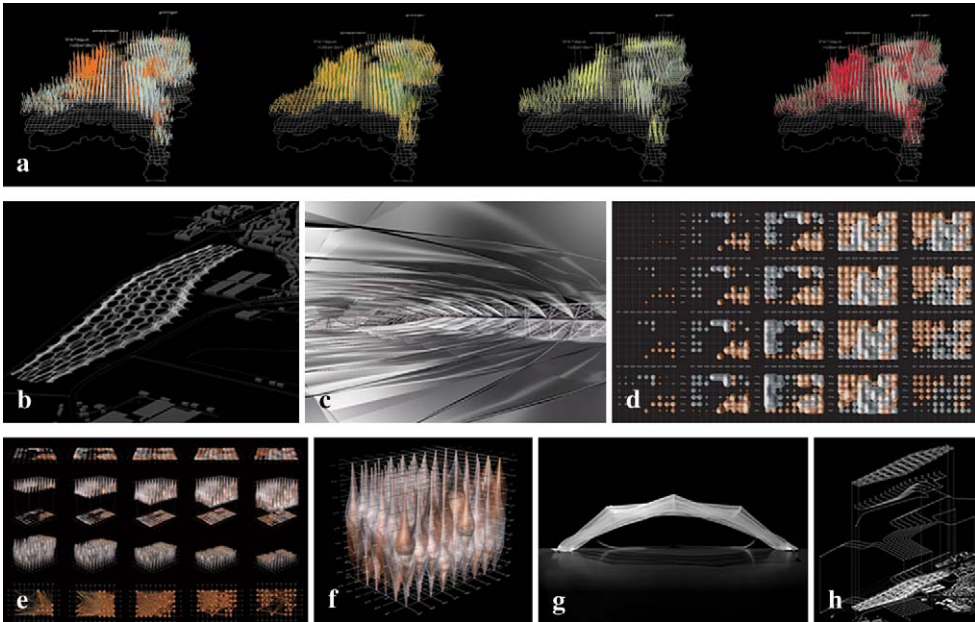


Figure 10 The digital analysis of Case 5, Post Agriculture (Photos courtesy of Bernhard Franken)

parametric data diagram shows the environmentally deduced structure, which looks like a generated and changed state.

4.2.5.2 Information. The last formed large structure may change in its form along with changes in the site's environment because of temperature, humidity, etc. All of it through the control of a computer system. The changes of these structures may directly or indirectly pass the environment's information to the users in a given space (Figure 10b). Therefore, the entire design construction is not merely a static framework consisting of materials with a different feel and look. It also provides a presentation of a new material called information (Figure 10c).

4.2.5.3 Generation. The initial 2-D dynamic illustration of the density analysis was converted to a quantified analysis diagram of tendency variation, which is affected by various condition factors. In Figure 10d, one can see the changes of various environmental factors and an induced organic mode for a relationship among the effects. The final pneumatic form was gradually generated during analysis (Figure 10e and f). At the same time, the dynamic environmental factors also became the deformation parameters, which control the design form's structure. The

design form continuously generates different states and evolutions because of these factors (Figure 10b).

4.2.5.4 Fabrication. As shown in Figure 10g, the object that made up the design and construction forms was investigated and designed, mainly using components that could be constructed – eventually. The design of the pneumatic surface, the test of the special object and the design of the fabrication method all play an essential role in the design process. The tectonic relevance to how the structure’s construction was completely put under a framework and then built was investigated (Figure 10h).

5 Digital tectonic validation

As mentioned in the methodology section, it is important to include digital examples from experienced designers who have many completed building projects under their belt that were influenced by their traditional tectonic training. Here, in order to illustrate the more universal utilization of the four digital factors in the tectonic processes, they are analyzed in the cases numbered six to ten. Please note that there is not enough information in the original documents provided by the designers to describe the motion factor in Cases 8, 9 and 10, the information factor in Cases 8 and 9, the generation factor in Cases 6, 7 and 10, and the fabrication factor in Cases 6, 9 and 10. This paper, therefore, does not include these analyses but they are being considered for future study.

5.1 Motion

Case [6]: In the analysis of the site planning, the grid and contour of the construction site were computer simulated. The shape of the design was then obtained by applying gradual changes as shown in Figure 11a. Figure 11b shows the grids formed by superimposing urban textures from various design periods. The grids were then twisted and deformed to form the range and layout of the final site plan. Simultaneously, the correlation among the higher levels of the site was also differentiated.

Case [7]: The design form of this architecture derives from the concept of ‘Bleb’, and molds a free form similar to bleb. The skin design of the

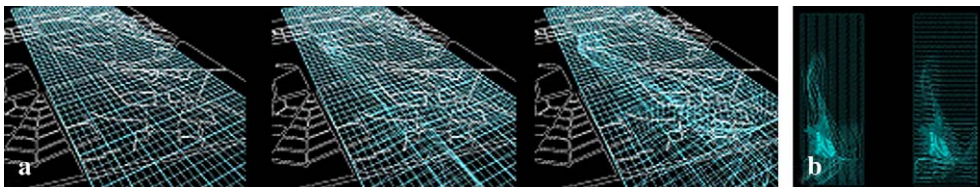


Figure 11 The concept diagram of Case 6, Hsinchu Museum of Digital Arts

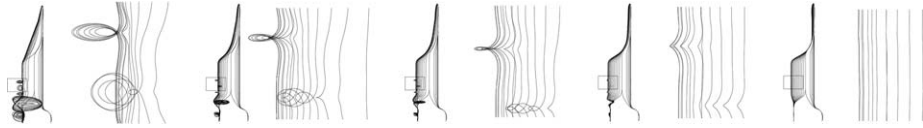


Figure 12 The concept diagram of Case 7, Eyebeam Museum of Art and Technology (Photos courtesy of Greg Lynn)

architecture is completed by operating a computer software program called Maya. The design model is obtained in the dynamic process generated by 'Bleb' on a line. Figure 12 shows the twisted states of the line to various degrees and the corresponding forms of the skin.

5.2 Information

Case [6]: The concept of this design is to create a new pattern with a 'physical museum as a base and a digital complex city as an extension' and hence create a museum of digital art that will inspire the development of a digital city. To build up a prospective digital and cultural network of technology-oriented art to present at various applicable levels the museum utilizes various types of multimedia, including video tape, film, text, sound, and interactive text and pictures. The communication of information, as in this work, has therefore become a key design element. To present the integration of physical space and the virtual world, and the concept of the hyperspace exhibition inter-networks, both the external wall and the interior space of the architecture use information as the major material. This is shown in Figure 13a, b and c.

Case [7]: This is the architecture of a museum of digital art and technology with information presented by the architect as the major material for the skin. The skin layer of the architecture is employed to communicate and provide information. The external wall consists of a myriad of electronic glass plates, which display 256 grayscale color schemes. The computer controls the displayed contents and lets the exterior of the building communicate dynamic information and images. Figure 14a and b shows the various simulated architectural skin-effects by using various kinds of information.



Figure 13 The spatial representation of Case 6, Hsinchu Museum of Digital Arts

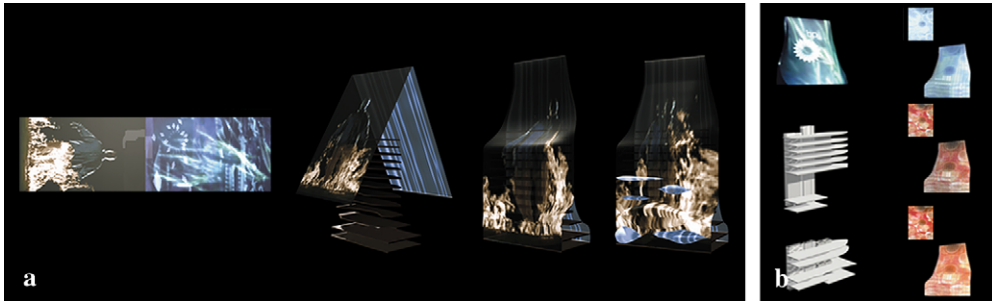


Figure 14 The spatial representation of Case 7, Eyebeam Museum of Art and Technology (Photos courtesy of Greg Lynn)

Case [10]: This is a museum that manifests the integration of art and media. The architect employs the external wall, which is punched with holes, and controls the shifting light rays coming through to the inside by using computers to open and close the shutters, thereby creating spaces with different atmospheres. Meanwhile, the outward appearance of the architecture is presented as a stage that displays dynamic information. Also, the inner walls and floor are made of polyurethane because it serves as the best medium for projecting the information. See Figure 15a, b and c.

5.3 Generation

Case [8]: The integral shape of the subway design is generated automatically by the computer. The architect calls this concept 'the architectural seed'. An artificial intelligence (AI) system is employed to automatically generate the shape of the design in the major design process (Figure 16a, b and c). The conditions and design requirements of the construction site were entered into an auto-generation computer system as restrictions and generating rules, from which the system can develop and organize the design shape by itself. Figure 16d and e shows the shape that is generated by the computer automatically.

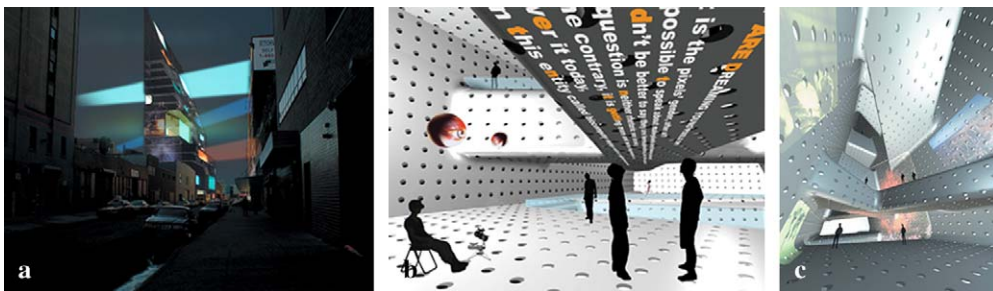


Figure 15 The spatial representation of Case 10, Eyebeam Museum of Art and Technology (Photos courtesy of MVRDV)

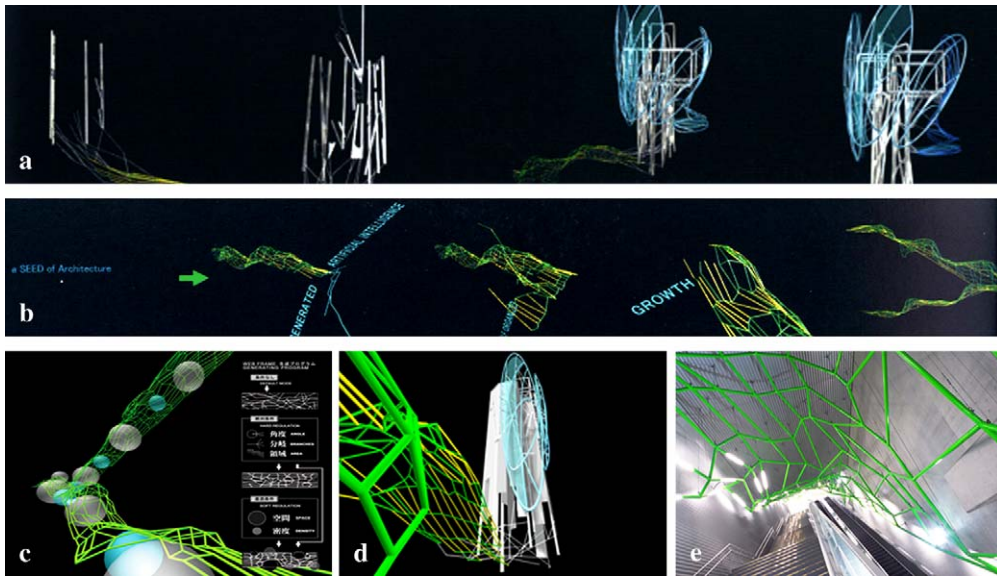


Figure 16 The concept diagram and spatial representation of Case 8, Subway Station IIDABASHI (Photos courtesy of Makoto Sei Waranabe)

Case [9]: AGORA is a device that integrates sound and architectural space. The integration of sound into a space becomes one element of the framework of the production. In the beginning of the creation of the shape, the computer software simulates the routes of the pedestrians, which are configured in such a way that they will not intersect with each other (Figure 17a). Once the 2-D routes are formed, they are collaged onto the picture surface of the construction site and the whole is then converted to a 3-D device, as shown in Figure 17b and c.

5.4 Fabrication

Case [7]: This is a special mass structure that does not have any columns and is supported mainly by a special external wall and the floor. Through the use of CAD/CAM technology, the architect uses RP to



Figure 17 The concept diagram and spatial representation of Case 9, AGORA Motion Space (Photos courtesy of OCEANnorth)

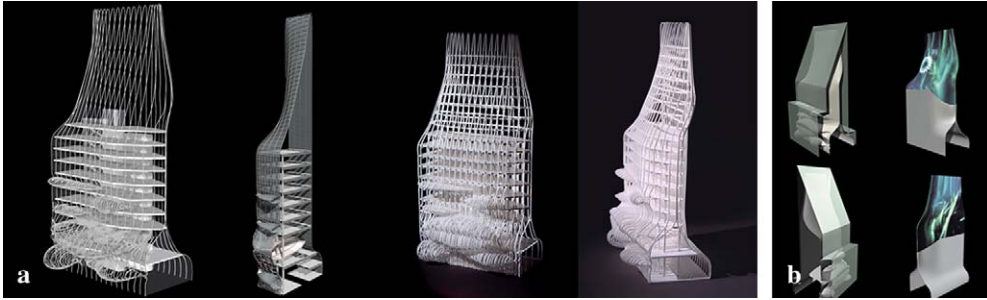


Figure 18 The CAD/CAM fabrication of Case 7, Eyebeam Museum of Art and Technology (Photos courtesy of Greg Lynn)

output the computer-generated model of the external wall structure for the purpose of designing and investigating its construction. The study model of the external curtain wall is shown in Figure 18a and b.

Case [8]: Once the integral design shape of the Subway is generated by the computer AI system, the computer-generated data is then used to create models (as shown in Figure 19a and b) by using a laser stereogram. The model is then sent to the factory to make precise components that can be assembled later at the construction site (Figure 19c).

6 Conclusion: new tectonics involving the classic and the digital

Architectural theory has evolved over time, to reflect the development of new materials, new construction, new structures, new philosophies, new social-cultural contexts, new scientific findings, and, of course, new technology. Especially, digital technology is not simply a new design tool but a new design medium; in other words, it is not only a new way of design making but also a new way of design thinking.

In this study, classic tectonic theory is shown to evolve, from the late 20th century, into the dramatic development of the digital medium. In

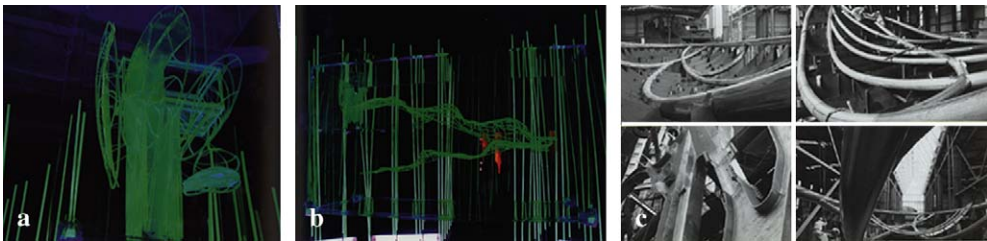


Figure 19 The CAD/CAM fabrication of Case 8, Subway Station IIDABASHI (Photos courtesy of Makoto Sei Waranabe)

the new tectonics, classic factors including joint, detail, material, object, structure, construction and interaction are still indispensable for realizing the design and construction processes. However, the case studies of this paper also suggest a slight redefinition of the scope of these classic factors because the predigital and digital process of design thinking and making are quite different (Liu, 2001). Along with the evolution of tectonic theory shown in these cases, some phenomena of digital tectonics have emerged to reveal the dynamic factors of motion, information, generation and fabrication. As a result, a preliminary framework for a new tectonics is proposed. In this set of new tectonics, seven classic and four digital factors form a whole and interact with each other.

6.1 Toward a theory of new tectonics

This case study simply scratches the surface of the digital development of tectonics. The classic theory of tectonics was developed from the middle 18th century to the late 20th century. To add new ingredients into this venerable and profound body of work is extremely serious work. Obviously this research is limited in several regards. As mentioned previously and repeatedly, many cases selected in this paper did not provide sufficient textual and figural documents to be analyzed. The digital phenomenon and factors proposed in this paper should be re-examined in a more systematic, intuitive and interactive research methodology. This should include cognitive experiments and the participatory observation of all designers who intend to explore the digital medium in both the design and construction stages. Furthermore, these case studies illustrate some correspondence between the two groups of tectonic factors: material and information, construction and fabrication, and interaction and motion/generation. Regretfully, the inter-relationship between the classic and digital groups of factors remains unclear and therefore needs further investigation. Finally, there are so many kinds of digital design at present: physical, virtual, and hybrids of the two as well as built, unbuilt and unbuildable (Harbison, 1993). In a sense, these design criteria and intentions heavily influence tectonic thinking and strategies in the design and construction processes. However, this paper is not able to address the important issue of tectonics physicality and virtuality. The above discussions are in fact some of the limitations of this research and thus deserve to be studied in the near future.

6.2 Implications to creativity

The design thinking study with regard to the definition, mechanism and process of design creativity is still mysterious but nevertheless

of central interest to the field of cognitive and computational theory of design. Many studies attempt to understand the cognitive processes underlying the creative behavior of human designers and, as a consequence, discuss the ability of computers to mimic and enhance the designer's creativity. Recently, we have begun to realize that making variations of existing and stereotypic choices is the key to pursuing creativity (Hofstadter, 1985). On the one hand, the strategies to make variations from different points of view include various ways of extending the boundaries of knowledge (Gero, 1996; Sosa and Gero, 2004), finding new problems rather than solving existing problems (Csikszentmihalyi, 1988; Simon, 1988), producing something we did not think of at the start of a project (Liu, 2002b) and working differently as we go through the processes starting as a novice and progressing to become an expert and then a creator (Gardner, 1988; Huang, 2004). On the other hand, creativity also belongs to the inter-relationship between personal and social-cultural levels of thinking (Csikszentmihalyi, 1996). Therefore, beyond personal creativity, knowing how to make variations in the knowledge domain of social and cultural boundaries is another important direction in which to address creativity (Liu, 2000).

Digital technology, not simply as a design tool but as a design medium, enables human designers and their social-cultural settings to produce unknown ideas during the design thinking process (Mitchell et al., 2003; Liu, 2003b, 2005). As we believe the digital age will change the design world even more dramatically than it has done so far, we ask what else can the digital medium stimulate or associate in regard to creative design? According to the above literature the new tectonic framework will play a possible role in pursuing design creativity in the future. The tectonic analysis is used in both the personal and social-cultural thinking of architectural design. Therefore, the factors and framework of tectonics have strong ties to the elements and processes of design thinking and creation, in terms of domain knowledge. Because of digital breakthroughs new tectonic factors will inevitably excite new ways to perceive domain knowledge. New ways of thinking and making domain knowledge will inevitably excite variations, extensions, and the as yet unknown. Consequently, the transitional processes for problem-finding/solving and the novice/expert/creator might have other alternatives that are as yet to be defined. In summary, the new set of the tectonic framework relates to the redefinition of domain knowledge for both personal and social/cultural design thinking. This will be the long-term future study of the current research.

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