# Digital-Green architecture: a new design process that integrates digital technology and sustainable concepts

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## Abstract

The trend of digital freeform and the awareness of environmental issues have propelled architecture to a higher level by comprehensively merging new technologies and green concepts. These observations suggest that we need a new structure for understanding the design process that integrates digital technology and the sustainable concept. Instead of dealing with micro issues, the question is whether it should be more concerned with the comprehensive fusion of a new design processes and the overall interactions of digital technology and sustainability thinking. This could elevate the design process from a disconnected level to a more general and comprehensive level.
*Keywords: Digital-Green, design process, digital technology, sustainable concept.*

## 1 Introduction

With the advanced technological capacity of computing, calculation and simulation, the rationale of contemporary architecture should not be directed only towards the aesthetic and functional aspects, but more efforts should be invested in carrying out the concepts of habitability, self-sufficiency, and sustainability [1, 2]. With the improvement of technologies, architects and researchers such as Frank Gehry, Mark Burry, Larry Sass, Branko Kolarevic et al. recognized the progressive needs for new digital design process when using digital CAD/CAM technologies, Rapid Prototyping (RP) and Computer Numeric Control (CNC) as new design media [3–8]. By operating and applying new digital media in the design process in a more efficient way, one also needed to develop a new design and construction method to satiate the new needs.

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Therefore, the traditional design process - schematic design stage, design development stage, detail design stage and construction stage, evolved with the new structure of digital design process. The new four stages are broadly applied in the digital design process-computational concept design, analysis, manufacture and assembly method [9].

The development of the green concept has advanced from linear focus on energy saving to "non-linearity" [2, 10, 11]. Buildings need redesigning to be more self-sufficient and self-organized and to be generating renewable energy themselves. Technological development has raised the boundary and enriched the field with extraordinary knowledge and potential and this has made the impossible building become possible [12]. Traditional sustainable design process of site analysis/planning, building forming, envelope developing and Finishes/technical supports, also needs to advance in association with digital technology [13–16].

Over the past few decades, the approach of sustainability has shifted to include the integration of digital technologies and self-sufficient green thinking. While architecture has taken a leap into the digital age, research and the way architects approach sustainability, has also been transformed by the new technologies. In the 90s, Yeang [17] (1999) described an ecological building as 'a kind of living organism' responding to its surrounding environment. Some digital sustainable forerunners, such as Norman Foster with his Reichstag Dome, etc., were clearly aware of the significance of sustainability. Kolarevic [2] (2004) also suggested that curvilinear forms and the appreciation of sustainability are both important approaches. Peter Testa and Ove Arup's [18] Carbon Tower was presented as an energy saving example of digital technology. By transferring technology from the textile to the highly-compressed carbon fibre reinforcement of the external helix, the architects demonstrated that vertical columns between floors could be eliminated. Steven Holl's [19] (2005) Silver Water Drop revealed his ability to blend architecture and landscape while maintaining the digital freeform with recyclable and natural-finished stainless steel material that echo Yeang's [19] (1999) idea of convening a dialogue between a building and its environment. Also, the design of the rotating skyscraper, by David Fisher [20], introduced prefabricated floor components and a self-powered system using wind turbines. The architecture profoundly embodies the concept of digital motion in a building and advanced the application of technology and green thinking. Digital techniques, such as 3D computer modelling, CNC technology (Computer Numerical Control), and laser cutting, provide cost-effective production methods for architectural applications. These new methods allow the pre-assembly of building components saving waste and reducing building costs. Furthermore, the higher technologies allow architects and scientists to experiment with new materials during the design process that might better suit the sustainable needs. These observations suggest that we need a new structure for understanding the design process that integrates digital technology and sustainable concept in the Digital-Green era.

## 2 Problem and methodology

During the last ten years, architects started to design buildings with the integrated methods of new CAD/CAM technologies. The new analytical software with advanced computing, calculating and simulation capabilities is the backbone of the digital age. Some of them were also paying attention to the gradual progression of sufficiency and sustainability. It is time to examine if the merging of the new technologies and the green concept would redefine digital architecture in a comprehensive perspective. Nowadays, people have become more perceptive and aware of environmental issues and new design thinking needs to accommodate the need for both digital and energy savings. These trends lead researchers to face the new challenges of how digital architecture will deal with the issue of sustainable innovation. However, while digital technology increasingly incorporates green concepts in the design process, one aspect of much current digital sustainable architecture is still viewed as narrowed down to a one-sided technical green concept; a machinery add-on to a building or a hi-tech surface decoration [2, 21]. Digital sustainable architecture does not imply the combination of new technologies to sustain the building or the adoption of another technique to design projects, but the process and interaction between digital technology and the sustainable concept. The digital free-forms integrated with these technologies are often innovative and some appear as the direct answers and new approaches to digital sustainable design.

Given the project examples above, there are still certain levels of disconnected themes of the discussion pertaining to design process. Through the discussion of "digital and sustainable architecture," architectures have to re-evaluate the new structure of design process for broader sustainable needs. This could elevate the design process from a micro to macro level. The question is whether architects should be more concerned with the comprehensive fusion of a new design processes and the overall interactions of digital technology and sustainability thinking? What one needs to know is, should they be mere green building standards or expressions of freeform or true digital sustainable designs as perceptions of the merging of digital technologies with the new sustainable movement? The purpose of this paper is to shift perspective from the design of a digital sustainable object to the understanding on an extensive design process that integrates the digital technologies and green aspects. What is more important is to emphasize a broader range of issues in design process that intimately bonds digital architectural manipulation and sustainable expressions.

The main purpose of this research is to determine whether digital freeform, integrated with new technologies and new ecological needs, may contribute to the sustainable needs of New Digital-Green design process. By using case studies, the three steps to approach this research are: (1) to conduct a wide investigation of case studies to make a comprehensive evaluation of the new factors for the analysis of new design process; (2) to understand the logics and characteristics of a new digital-green design factor; (3) to analyze the basic design process in terms of from general, sustainable, digital and the preliminarily digital-sustainable architecture to obtain a new model of Digital-Green design process.

## 3 Examination of cases

The logic of choosing these ten cases is to explain the following principles. First, projects are selected from various countries based on an impartial perspective. The distributions of the locations range from Asia, Middle East, America, to Europe. Second, the structures embrace different architectural scales such as private residence and large-sized public stadium. Lastly, the chosen architects are sophisticated in experimenting with designing digital architecture with elements of sustainable issues. By analyzing the design processes that involve digital manipulation and sustainable design thinking, the examination of the ten cases aims to explore various characteristics of the architectures. From the ten projects, the relationship between digital technologies and sustainable characteristics plus the logic of design processes are explained with broader applications.

## 4 Factors for analysis design process

Based on the case study, the preliminary structure from digital or sustainable architecture might be insufficient for the needs of digital-green design process. It is necessary to apply new factors in generalizing the new design process to integrate both digital technology and sustainable concept. In creating the original design process, the knowledge of the five classic factors, detail/joint, material, object, structure, and construction, were categorized [22–29]. After rethinking the five classic factors, a set of seven factors: the joint, detail, material, object, structure, construction and interaction were proposed [30]. This redefined the classic elements with the backdrop of digital thinking. Through the digital design process with new methods of assembly, five digital factors were proposed including concept, manipulation, construction, form, and space [29]. In addition, four new digital factors are also sorted out which are motion, information, generation and fabrication [31].

Moreover, with the improvement of technology and the developing of green thinking, the use of computers and CAD/CAM technology in the design process transformed the expression of digital architecture into the combination of digital and sustainable operation. With the understanding of both set of basic factors, the commonality of those factors is analyzed through comparisons, which support the formation of a new design process skeleton. Considering the operation of sustainable factors, the study would address only the key areas based on structure, building form (envelope), electrical power, technical principles (ventilation, heating, cooling, lighting, etc.), environment (water, waste, energy, noise), site (microclimate, green space) and materials [13–15]. However, this analysis is not specifically concerned with the pure sustainable mechanical issue, but rather addresses the new design process that integrates digital technology and sustainable concept. By using the digital design manipulation technique merging with green thinking, the new method of design process is different from the original expression of digital architectural manipulation. Therefore, the new five Digital-green factors proposed in this

paper are construction (structure), materials, object, interaction and form [22–31].

This research attempts to broaden the digital-green phenomenon from digital expression, therefore the five new factors are applied to analyze the cases.

The following definitions are of the five new factors applied in the research:

- Construction:

With the aid of computer technology and 3D modelling techniques, the original expression and definitions of structural appear to have changed dramatically not only with high-level technologies but also with energy-efficiency [14, 23].

- Materials

Based on the new construction methods of 3D modelling, animation, simulation and deformation, the selection of material has influenced its ability to fabricate the flowing surface and the application of specialized structural effects. The use of materials is mostly concentrated on looking for smoother textures and such aspects as transparency or metallic forms in the digital environment. When advanced to the digital-green period, the material selections for digital use may also have the duality of sustainable consideration [22, 32].

- Object

By making the architectural whole from architectural parts, those that were originally defined as columns, walls, slab, doors and roof…etc. were redefined by mixing the functions for both free-form and sustainable needs. Therefore, the parts free-formed with the aid of CAM/CAM technology, are also re-defined or reformed in an attempt to match the new needs of sustainability [15, 23].

- Interaction

The relationships between construction site and architecture, green space and architecture, and also with people and form are emphasized here [29].

- Form

With the new design thinking and process, concern for sustainable needs and computer-aided technology, the form of architecture, or the use of building envelops may be redefined in the digital-green environment. Walls, roofs, floors and other construction components are all effective in the transformation to the new spatial form [22, 29]. Through the assistance of green thinking and the new techniques, the form of the digital flowing surface may co-exist with sustainable needs.

## 5 Evolution of design process

### 5.1 Design processes

The factors of design process are analyzed by case studies during step 1 and 2 (Table 1). The design processes in Figure 1 [33] and 2 [6] show the change of

Table 1: Index of ten case studies.

| Case # | Project Name | Architect(s) | Location | Year |
|---|---|---|---|---|
| 1 | Phare Tower | Morphosis | Paris | 2012 |
| 2 | The Dynamic Tower | David Fisher | Moscow | 2010 |
| 3 | Bird's Nest | Herzog & de Meuron | Beijing | 2008 |
| 4 | Zaragoza Bridge Pavilion | Zaha Hadid | Spain | 2008 |
| 5 | Silver Drop | Steven Holl | Connecticut | 2007 |
| 6 | BMW WELT Munich | COOP Himmelb(L)au | Germany | 2007 |
| 7 | Carbon Tower | Peter Testa and Ove Arup | Dubai | 2005 |
| 8 | Yokohama Port Terminal | Foreign Office Architects | Japan | 2002 |
| 9 | Swiss Re Headquarters | Foster and Partners | London | 1999 |
| 10 | Reichstag Dome | Foster and Partners | Berlin | 1999 |

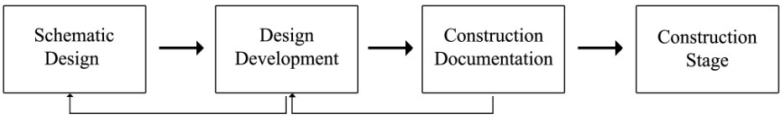



Figure 1: General design process [33].

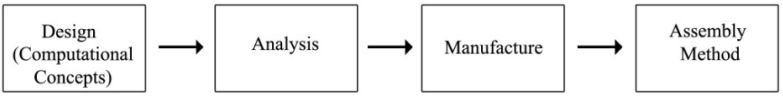



Figure 2: Digital design process [6].

design process from traditional to digital architecture field because of the different manipulations. It is also very important to explore the design process based on sustainable methods as shown in Figure 3 [34], which is almost parallel to either traditional or digital architecture in the past. Based on the analysis of the previous design processes and proportional information of the case-study factors, the design process of merging digital technology and green aspect is initiated. To maximize the capacity of a dynamic digital design process, the features of computational design media and digital graphics (topological surface, isomorphic field, etc.) allow architects to shape the form freely and create a more functional skin/envelope. Therefore, the emerging procedures of conceptual design, computational concept and envelope study provide new possibilities to the unexpected new forms and sustainable influence in the new Digital-Green design process in Figure 4. This new design process is anticipated to help designers to merge both digital and sustainable aspects in fashion during the design thinking and design process.

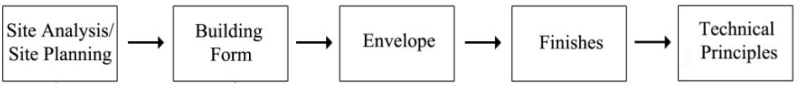



Figure 3: The sustainable design process [34].

a b

Figure 4: Case 4 (a) and Case 9 (b). Photo credit: Case 4 (a): Luke Hayes; Case 9 (b): Adrian Welch.

Figure 5: Case 4. Photo credit: Zaha Hadid Office.

### 5.2 Discussion of ten cases

#### 5.2.1 Form

With the aim of technology and the development of green thinking, the form could be full of dynamic characteristics and at the same time work sustainably. In Case 1 and Case 4, the evolution of the freeform was determined by the consideration of responding in accordance to the path of the sun for the heat gain and glare. The curvilinear double skin on the south façade and the flat and clear-glazed north façade show its purposes of minimizing heat gain and maximizing interior exposures to natural daylight. Such as Case 2, each floor rotates independently with the power of wind turbines fitted between each floor, which not only provided effective power to the surrounding environment, but also allowed the free form to express itself with sustainable needs. Case 9 (Fig. 4) demonstrates how the spiralling form could be responsible for guiding the wind flow up the building for better ventilation. This helps to demonstrate how a digital architectural form full of expression is not limited in shape, but now has more capacity for the need to react with the environment.

#### 5.2.2 Material

By using computer technology and simulation, designers could manipulate different kinds of materials to achieve the dynamic form one desires to approach but also have sustainable value for the environment. Case 4 shows the consideration of using new innovative sustainable triangular panels made of

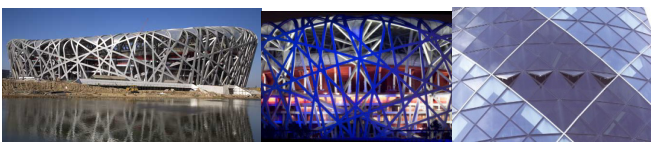
glass fibre concrete to envelop the outer skin of the building. Case 5 demonstrates how a digital freeform stainless steel building could also be sustainable with heat absorption reduction when the stainless steel improves to be recyclable and naturally-finished. By transferring weaving technology from the textile industry to architecture, the characteristics of the carbon fibre material were redefined to form the structural helix for the exterior surface of the Carbon Tower in Case 7. The use of mirrored cone shows how the project in Case 10 effectively decreased the carbon emissions of the building with the use of daylight on reflective material for heat gains. With the aid of computer simulation by CAD/CAM technology, this recycled/raw material made possible an increase in tensile strength that is up to five times that of steel. Considering that there is no need for columns between floors because of the extremely compressed characteristics of the material, this energy-saving advantage helps to explain the importance of using new sustainable materials with the aid of digital design processes to reconfigure traditional architectural elements.

### 5.2.3 Object

Based on the concern for both digital and green, one could see the definitions of basic architectural elements such as roof, façade, column or window becoming vague because of the comprehensive functions and roles. Such as Case 3, when the structure integrated the stairs, walls and roof all into one cohesive system, it also served as both structure and façade with its load bearing grid-like formation. The green features of the rainwater collection system also emphasize the dual functions of the roof in Case 3. To encourage the continuity of natural ventilation through the whole building in Case 6, the façade and the Double Cone column structure merge together with the roof with the solar modules integrated on the surface, the original architectural elements are replaced with the new forms and multiple functions. In Case 9, the functional parts such as the high performance solar glass façade, the ventilated floor plan, the air flow entrance and the lung-like light well demonstrate the multi-functions of the object, which offer a new reason to make an architectural whole, not only with high-level technique for its modern look but also to provide energy-efficiency.

### 5.2.4 Construction

The aim of computer technology and the needs of sustainable concern offer a completely new way to explore different possibilities in the areas of



a b c

Figure 6: Case 3 (a) (b) and Case 9 (c). Photo credit: Case 3 (a) (b): Ben McMillan; Case 9 (c): Luke Hayes.

construction. This feature is particularly evident in Case 2 when the whole skyscraper is to be built entirely from prefabricated parts that are made digitally for fast construction and energy saving. In Case 6, the project uses rectangular pipes to support the glass panes directly instead of traditional round pipes, which certainly reduces steel consumption in construction. Moreover, because of the new innovation of extremely compressed material by technologies, there is no need for columns between floors in Case 7. This helps to explain how merging digital technologies and sustainable concerns not only give us new ways of construction but also leads to new manipulations in design process and thinking.

### 5.2.5 Interaction

The project in Case 1 attempts to produce a close interaction between the environmental context and green space with the crown of wind turbines on the roof garden to grow the building's own ecosystem. One example is the shark scales envelope of Case 4, with its shingle's different ways of generation allowing for leading natural light and visual contact with the river, which demonstrate its relationship to the surrounding environment visually and sustainably. In Case 5, with the merging of high technology with green thinking, the ozonation bubbling system and green roof system on the rooftop brings natural light to the interior building and also corresponds to the surrounding site. From Case 8, one can observe how architecture and green space interact with each other. To express itself as an extension of the urban site, this linear structure puts the green roof of the building into a continuous relationship with the surrounding public park and waterfront, which connects the site to the rooftop green space, links the city to the sea, and also interweaves the interior and exterior. Hence, the interaction between this arrangement, green space and people, emphasizes how digital architecture produces more than just a fluid shape, but also interacts with the surroundings with environmental purpose.

a b

Figure 7: Case 4 (a) and Case 8 (b). Photo credit: Case 4 (a): Zaha Hadid Office; Case 8 (b): Mami Sayo.

## 6 Conclusion

This research has pointed out the need for a higher level interrelationship between digital design process and sustainable concept in the digital-green age. The recent digital sustainable architecture is more concerned with disconnected issues. The digital-green evolution in architectural design has been supplanted

not only in the design manipulations, but also in the evolution of merging digital technology and sustainable aspects entirely. With such understanding, a new design process of merging digital technologies and sustainability through new factors are applied to the study (Fig. 8).

By merging the digital design manipulation technique and green thinking, the new method of design process differs from the original expression of digital architectural manipulation. It is essential to emphasize a broader range of issues in design process, bonding digital architectural applications and sustainable expressions. This could extend the design process from a disconnected level to a more general and comprehensive level. This might further lead to the establishment of a prototype or conceptual model created by computer simulations or modelling to test the potential of the new factors and the new design process for the further investigation. Through this process, we will have a closer understanding of the relationships between the new digital-green architecture with CAD/CAM technologies and the new green movement in future digital-green projects. By examining new design process as proposed in this research, future studies could have the direction for exploring diverse design media or manipulations for corresponding with digital and sustainable application. The result might influence the generation of future work and deliver some level of change through a freshly-integrated perception of new technology and sustainable design thinking.

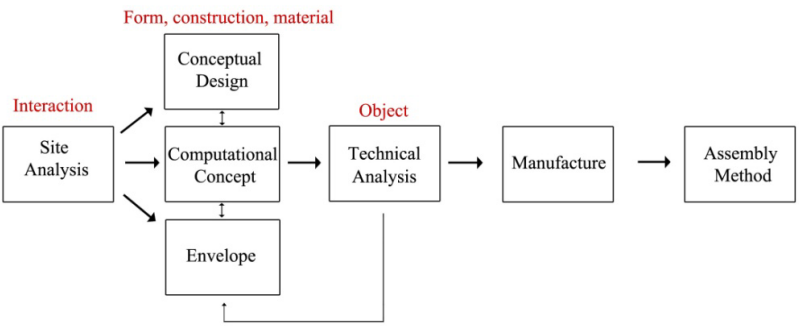



Figure 8: Digital-Green design process.

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