Tradition and Innovation in Digital Architecture

Reviewing the Serpentine Gallery Pavilion 2005

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Please write your aToday, in a moment when digital technologies are taking command of many architectural design and construction processes, it is important to examine the place and role of traditional ones. Designed by Álvaro Siza and Eduardo Souto de Moura in collaboration with Cecil Balmond, the Serpentine Gallery Pavilion 2005 reflects the potential of combining those two different approaches in the production of innovative buildings. For inquiring this argument, this paper investigates the development of this project from its conception to construction with a double goal: to uncover the relationship between analogical and digital processes, and to understand the architects’ role in a geographically distributed workflow, which involved the use of computational design and robotic fabrication technologies. To support this examination, the authors designed and fabricated a 1:3 scale prototype of part of the Pavilion, which also served to check and reflect on the technological evolution since then, which is setting different conditions for design development and collaboration.

Keywords: Serpentine Gallery Pavilion, Computational Design, Digital Fabrication, Wooden Construction, Architectural Representation,

INTRODUCTION

As Vieira observes (1995), manual processes imply the mental and physical activities that allow us to easier reach our intuition. The production of drawings by hand was - and still is today - at the foundation of many architectural projects. The tradition of such manual representations can be traced back to the XV century, when Alberti claimed that the architect’s role was to draw and not to construct their buildings (Carpo 2013). Lasting from the Renaissance, his notational system based on plan and section drawings have remained today as the most used normalized process to translate design into construction. Aside with these technical representations, sketching also has kept its importance as a privileged mean to bridge mind and hand, supporting the imagination and agile communication of architectural ideas. This is the main body of your paper. You can either add one paragraph at a time using the “(+)>” menu on the left side or fill it using “import paper”.

With the introduction of digital technologies in architecture during the 1960’s and 1970’s, comput-
ers didn’t offer much more than the emulation and automation of manual techniques to assist the development of conventional technical drawings. It was in the early 1990’s, when architects started to explore the conception of architectural design ideas with the help of computers. For instance, the paperless studios at Columbia University were a declared move on using the digital as an alternative media to analogical ones (e.g sketching) to engage intuition and imagination. Since then, the evolution of the computational power and applications did not stop to grow. Today, digital technologies can assist at any stage of the architectural design process, from conception, to engineering, fabrication and construction.

The way architects are managing those possibilities is very diverse. In one extreme, there are those trying to resist them by insisting on the traditions of analogical representational tools and techniques. In the other, there are those expressing a universal faith in the digital and looking for exploring its full and exclusive potential of innovation in the design process. Between these poles, the majority of architectural practices set their own combination of analogical and digital tools aligned with the traditions of analogical-based design processes. Nonetheless, some practices like Frank Gehry, have innovated without denying neither traditional processes (e.g. sketching and physical modeling) nor digital ones (e.g. digitalization, parametric design or digital fabrication) (Lindsey 2002).

Research Topic
In this context, the present article summarizes the investigation and findings of a Master thesis developed by first author (Almeida 2015) on the Serpentine Gallery Pavilion 2005, which was designed by Álvaro Siza and Eduardo Souto de Moura, with the collaboration of Cecil Balmond (Figure 1). While the architects are known from their design processes rooted in traditions and analogical representations [1] [2], the engineer is known by his disruptive and digital integrated design methods (Balmond 2007). Thus, this paper seeks to disclose the way such different approaches came together in such project. By investigating that question, both through literature review, contact with direct sources and practical experimentation with digital technologies, the authors argue that the Serpentine Pavilion 2005 is an exceptional project to demonstrate that innovation can emerge out of the combination of traditional and digital pro-

Figure 1
Serpentine Gallery Pavilion 2005 designed by Álvaro Siza, and Eduardo Souto de Moura with Cecil Balmond - Arup, Photograph © 2005 Sylvain Deleu
cesses in architecture. At this age of accelerated technological evolution it is important to highlight that the “old” and the “new” do not have necessary to be in constant opposition. Indeed, the use of digital technologies in architecture can actually include traditional processes and still produce innovative results.

THE SERPENTINE GALLERY PAVILION 2005

Since 2000, the Serpentine Gallery in London has invited international architects every year to design a temporary pavilion in the gardens of the main gallery. The project is usually commissioned in January and has to be built and ready for opening in June, which thus gives six months to develop its design and achieve its construction. In 2005, the pavilion was conceived by the Portuguese architects Álvaro Siza and Eduardo Souto de Moura in collaboration with Cecil Balmond, a structural engineer at Arup. Besides the official book by Larner (2005), there is little bibliography available describing such singular collaboration and its resulting project. To investigate it, the authors contacted direct sources, like architect Tiago Figueiredo from Eduardo Souto de Moura’s office, who was the project architect in charge of the Pavilion, and Michael Keller, a former Vice-President of Merk Timber, which was the company responsible for the digital fabrication of the wooden parts of the pavilion.

Design Development

In Solà-Morales opinion (1997), contemporary architecture is characterized by its capacity to take advantage of scientifically and technological innovations. Thus, by looking at its formal and structural result, it seems possible to argue that the Serpentine Gallery Pavilion 2005 can illustrate that statement. However, a more in-depth review of its design process shows that it was not neither linear nor usual.

Known by their respect with the context and attention to building details, the architects desired this building to dialog with the big centennial tree that exists in the gallery gardens. With that in mind, the architects didn’t want the building to look high-tech, in opposition to the previous Serpentine Gallery Pavilions (Figueiredo 2015). From a simple rectangular grid, the design sketches evolved to a more organic twisted version, with the intention to create a more fluid look (Figure 2). Nevertheless, as stated by Álvaro Siza (Larner 2005), those twists weren’t made just for aesthetic reasons, but rather as a response to the natural slopes, directions and constrains of the site. The organic form of the building, resembling a crouching animal (Figueiredo 2015), made the architects decide to create a wooden building only with mortise and tenon joints (Figure 3). This kind of generative design process unfolded analogically through many sketches and conversations.

Figure 2
Conceptual sketches by Álvaro Siza for the Serpentine Gallery Pavilion.
Reacting to the architect’s proposal, Cecil Balmond suggested a more intricate and sophisticated lamella system, by offsetting every wooden piece, to create a more random look. Conscious of their lack of computational design capabilities and the limitations of two-dimensional drawings to capture such design intention, the architects turned into LT Studio, a 3D visualization company based in Porto, in order to study and evolve the overall form of the pavilion. The first digital model of the pavilion was done with Rhinoceros but, given that it was not a parametric representation, every minor change made to the design implied the re-modeling of every piece. To overcome that limitation, Cecil Balmond and its Advanced Geometry Unit (AGU) at Arup took the responsibility to develop a computational model of the final design of the pavilion in Arup. Knowing that wouldn’t be able to precisely model each one of the different wooden members, the architects defined a list of constraints and parameters. This allowed them to have some degree of control through the final modeling, even though they didn’t took part on it. Regarding this, Tiago Figueiredo (2015) says “our concern was to look to the pavilion as a whole and not to the specification of each piece”.

**Constructive Development**

Coming from the interactions between the architects and the engineer, the structural concept behind the Serpentine Gallery Pavilion 2005 relied on the reciprocity principle (Sakamoto and Ferré 2008). As explained by Pugnale and Sassone (2014), “the principle of reciprocity is based on the use of load-bearing elements which, supporting one another along their spans and never at the extremities, compose a spatial configuration with no clear structural hierarchy”. Led by Cecil Balmond in London, the AGU team applied that principle to the lamella system to achieve the necessary structural stability of the complex form of the pavilion (Figure 4). This endeavor originated a new model of the pavilion, based on a mathematical relationship between the constraints given by the architects and the position of each part on the three-dimensional grid. A script was then applied to create 36 coordinate points for each piece and thus automatically generate each of the 427 differentiated wooden components (Sakamoto and Ferré 2008).
Fabrication and Construction

The digital fabrication of the pavilion was made in Germany by the Finnforest Company, which was later divided into two different companies, MetsaWood and Merk Gmbh. To handle their variable size and slanted edge thickness, the pieces were milled using 5-axis KUKA robotic arms, running directly from digital data. Avoiding the production of printed drawings, the workflow was totally digital, and required a straight collaboration between the engineers from Arup and the Finnforest manufacturers to integrate fabrication parameters in the design model. As Michael Keller told the authors (2015), the entirely digital process allowed getting all pieces done in a small amount of time and with a great degree of precision (Figure 5). The robotic arms were programmed to detect the laminated veneer lumber boards (LVL), which was the material used to make the pavilion due to its lightweight, and automatically change its end-effector for the different operations (Menges 2006). Curiously, Martin Self, a member of the AGU team by then, acknowledges the Serpentine Gallery Pavilion 2005 as the first robotically fabricated building [3]. All the structural parts were then transported from Germany to London and assembled at the project site. Due to the irregular nature of the structure, the building had to be assembled in a strict order to avoid collapsing during that process. Once it was finished, the structure could hold itself just by the mortise and tenon joints. However, for extra safety reasons, the pieces were also fastened with bolts and nuts.

Remarks

The built pavilion emerged from the successful articulation between two different approaches to architectural design. Indeed, the contextual and material interests of the architects unfolded through sketching and, without any digital influence, resulted in the imagination of an architectural solution featuring a complex form and structure. To make it real, the use of computational design was then essential to think and evolve such design intention towards a particular solution of a wooden lamella system with a unique expressive effect. Finally, digital fabrication was the only solution capable of solving on time and with precision, the materialization of all the different pieces. Besides assisting those stages in the design process, the digital also provided the media...
Map of the geographically distributed collaboration behind the production of the Serpentine Gallery Pavilion 2005.

to support a geographically distributed collaboration through different European countries (i.e. Portugal, UK, Finland and Germany) (Figure 6). Indeed, ten years ago, the different expertise required for this project could not be found in a single place. The tectonics of the Serpentine Gallery Pavilion thus clearly prove how traditional interests and processes can be expanded by means of digital technologies, driving towards innovative built results.

**EXPERIMENTAL WORK**

For a better examination of the Serpentine Gallery Pavilion 2005, the authors conducted an experimental work on digital design and fabrication. The goal was to understand the geometric challenges and the contribution of digital technologies in the process, while investigating the possibility of, ten years later, doing all the tasks in a single geographic location.

**Design**

In this experiment, the authors identified three parts of the building - a corner, a flat part of the roof, and a curved one - and developed the corresponding digital models (Figure 7). This task revealed all the geometric complexity behind such a clear and apparently simple structural concept. Due to the virtual double curved form of the Pavilion, its direct conversion into a structural lamella configuration gave origin to a myriad of differentiated wooden pieces, many of which, featuring a complex surface on their contour depth. Just like in the real pavilion, the first step was to create a three-dimensional shell from a two-dimensional grid plan in Rhinoceros, with every interception on it corresponding to a different elevation. Then, each structural piece was created through offset, intersect, loft and extrusion commands. For modeling all the mortise and tenon joints, the authors used the constraints given by the architects, such as the maximum and minimum heights, and the length and the natural inclination of each piece.

**Prototyping**

As stated by Tiago Figueiredo (2015), during the search for the ideal formal and constructive solution for the Serpentine Gallery Pavilion, it was extremely hard to make physical models, due to the intricate nature of the structure. The high number of different pieces and the impossibility to get the true shape of each one of the parts from bi-dimensional drawings determined that almost no physical model was developed during that process. In order to overcome the limitations of traditional representation methods, the authors took now advantage of 3D printing technologies and produced a 1:50 scale physical model of the whole Pavilion, using SLS (Selective Laser Sintering) process (Figure 8).
**Fabrication**

From the three detailed digital models produced to study in depth the geometry and connection system of the structure, the authors decided that the double curved part of the roof would be the most challenging one to test the use of digital fabrication technologies and, more specifically, the capabilities of the robotic arm. Thus, the materialization of the structure at 1:3 scale unfolded through 3 stages: digital planning of the pieces, robotic fabrication and manual finishing.

In this experiment, the authors used a 6-axis Kuka KR120 r2700 belonging to the Digital Fabrication Lab (DFL) at the Faculty of Architecture of the University of Porto (FAUP), which has a 120kg payload and 2.7 meters of work range. Although also a Kuka robot was used to fabricate the original pavilion, back in 2005, the programming of the robot was more complex and would have involved the articulation between three different softwares (Braumann and Brell-Cokcan 2011). Now, in this experiment, the authors could take advantage of a single digital environment for designing and fabricating by using Grasshopper and the Kuka|prc plugin, running in Rhinoceros. By including a kinematic motion simulator and the automatic generation of the KRL code, the robotic fabrication could be executed by the robot without the need of using any other software.

Prior to the fabrication, all the pieces were scaled to 1:3 in Rhino, which allowed to be milled all at once from one MDF board with 22mm thickness. Using Grasshopper to define the geometries and KUKA|prc to program the motion of the robotic arm, the wooden parts were digitally fabricated within a couple of hours (Figure 9). The robotic arm was equipped with a milling tool mounted in the spindle, very similar to the one used in the fabrication of the original pavilion. It should be noticed that besides the irregular geometry of their contours, the lateral surfaces of the edges are variable ruled surfaces. For that reason, the 6-axis movements were a requirement for cutting out the pieces. Since the pavilion works as a reciprocal structure and the prototype was just a part of it, the pieces had to be fastened with bolts and nuts to stabilize their position. For covering the Pavilion, the architects used an acrylic panel attached to the wooden structure with a neoprene band below. For cutting those differentiated panels, this experiment took advantage of robotic hotwire process.

![Figure 9](image)

The robotic cutting of the wooden pieces at the DFL, with 6-axis movements.

**Assembly**

The assembly process of the prototype was easy and the morten and bolten connections fit all together (Figure 10). It was interesting to observe the continuity of the ruled surfaces across the edge surfaces of the different pieces. Thus, one can affirm that the prototype captured the different aspects of the design and fabrication process of Serpentine Gallery Pavilion 2005.
CONCLUSION

The research work presented in this paper investigated the role of traditional design processes in the digital era. To do so, the authors studied the design and construction processes behind the Serpentine Gallery Pavilion 2005, where traditional ways of understanding and representing architecture converged with advanced technologies to materialize an innovative building in wood.

The first lesson to retain from this project is the possibility to establish a symbiotic relation between analogical and digital technologies with a clear benefit for the architects. While sketching proved its validity to assist the architect’s mind in the imagination of a complex solution, the digital design and fabrication means were decisive to evolve and materialize it. Without such integration, the architects’ ideal vision could have been lost, or, most probably, several design simplifications would have to occur to make the project -for sure different- happen through conventional means. Methodologically, despite the switch of the process into the digital media and the geographically dispersed collaboration, Álvaro Siza and Eduardo Souto de Moura found a way to continue controlling the design development towards its materialization. As Tiago Figueiredo mentioned, even not directly controlling the computational design and digital fabrication tools, the architects had a key role through every stage of the process.

The experimental work developed by the authors confirmed the considerations made throughout this paper. On the one hand, it allowed realizing the difficult geometric challenges of the project, and experiencing the power of computational design to handle such complexity. On the other hand, reminding that it took only a couple of hours to robotically fabricate the 15 pieces for the 1:3 scale prototype, one can image the impossible task, in terms of time and craftsmanship, of fabricating the 427 different pieces of the structure through traditional methods. Also, it was interesting to verify that ten years after the Serpentine Gallery Pavilion, the technological evolution has created the conditions to produce drawings, digital models, prototypes and mockups in the same location. Given that architects tend to think through representations (i.e. graphic and physical),
the possibility to collapse into a single place what was by then a geographically spread collaboration, draws new conditions to develop architectural projects.

To conclude, one can affirm that in an age of continuously technological evolution, it doesn’t make sense to perceive the concept of innovation as an opposition force to that of tradition. Contemporary architecture, as a multidisciplinary area that requires the integration of different fields of work, certainly benefits from the synergetic process between traditional and digital tools. As stated by Tiago Figueiredo (2015) “it is for the best of architecture that we learn how to master the emerging digital technologies, nevertheless we may not let ourselves be dominated by them.” Thus, in the Serpentine Gallery Pavilion 2005, advanced digital technologies clearly helped to expand and materialize the creative vision of Álvaro Siza and Eduardo Souto de Moura. The story of this building is exemplar in the way it can serve to encourage academic and professionals to find natural ways of integrating advanced digital technologies in the curriculums and practices. At the end of the line, it is the architect’s judge that shall prevail, taking advantage of existing traditional and digital tools to fulfill his ideal vision for the built environment.

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