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TOWARDS AN HISTORY OF COMPUTATIONAL TOOLS IN AUTOMATED ARCHITECTURAL DESIGN

The Seroussi Pavilion Competition as a Case Study

NADJA GAUDILLIERE

¹*Laboratoire GSA, Ecole Nationale Supérieure d'Architecture
Paris-Malaquais, 75006 Paris, France*

¹*nadja.gaudilliere@gmail.com*

Abstract. The present research proposes a method to analyse computational tools at the architect's disposal and the potential technical bias they induce in architectural design. Six case studies will be used as a demonstration of the method's ability to highlight those biases and how architects and designers manipulate those tools to translate their architectural expertise into algorithmic design. Those case studies are the six answers to the Seroussi Pavilion competition, organized in 2007 by Natalie Seroussi, a Parisian gallery owner. Having a keen interest into computational design, she invited six architectural practices specializing in this field. As the six case studies answer the same design brief, it represents a particularly suitable opportunity to analyse the intricate relationship between architectural constraints, their translation into computational data and instructions and the programming tools used to do so. Through the analysis of four different aspects of the project - algorithmic tools/method, computational set-up, organizational chart and architectural design - several issues of the computational turn in architecture are discussed.

Keywords. Digital heritage; computational design tools; architectural constraints; programming-based spatial design; Seroussi pavilion competition.

1. Introduction: toward an history of computational spatial design tools

1.1. ALGORITHMIC DESIGN AS A TOOL FOR SPACE DESIGN

Throughout the last 50 years or almost, architects, urbanists, structural engineers and designers have been experimenting with the computer's ability, given a proper set of instructions, to generate shapes and other contents on its own. But beyond the fascinating ability of computers to create geometries from nothing but a few written signs, the objective for architects has become generating a relevant spatial solution to a given architectural problem using computational design tools. To achieve this, the instrumental issue is the translation of architectural constraints into an operable set of data and instructions, or in other words, into an operable

algorithm. But the structure of algorithms, alongside the coding languages used to create them, are fundamentally different of any other tool previously used by architects for space design. Therefore, architectural constraints such as program, context, structural loads and other are dealt with in a new approach, contributing to the renewal seen in architectural design as recourse to digital design methods spreads out. In light of these changes, understanding to what extent architects and designers resort to algorithms and computational design appears to be a major issue to tackle.

In order to tackle this issue, a key element to analyse is the computational design tool itself. If at the beginning of computational experimentation, architects shaped their tools for spatial design on their own, developing specific algorithms from scratch or almost for each project, in a more recent past the emergence of software such as Grasshopper or Processing has widely simplified the recourse to computational design methods. This has been followed by a blossoming of ready-made algorithms available to architects, granting access to elaborate mathematical and geometrical tools in an unprecedented way to designers untrained in these domains. This access has however been accompanied by a less sharp control of those tools, compared to those initially shaped by digital architects themselves. Lesser control of the programming tool induces more technical biases to be aware of in the translation of architectural constraints into data and algorithmic instructions. This situation calls for an analysis of what programming tools offer regarding architectural constraints translation and technical biases, a question scarcely discussed in the field of computational design.

1.2. THE COMPUTATIONAL FIELD IN ARCHITECTURE

Although the use of computational tools has in the last few years spread to a greater number of architects and designers, seminal research in the field has been conducted by a much smaller group of digital architects and designers. This group forms the core of a specific niche that has developed computational design through research projects, teaching and architectural practice for several decades. The variety of experimentations conducted within this group resulted over the years in very diverse architectural proposals, yet these designers were brought together by a common use of digital design tools, including programming tools, therefore earning the appellation of computational movement to the group (Menges & Alquist 2011).

The computational field in architecture is characterized not only by the common resort to specific design tools, but also by conditions that enabled research on this topic to blossom. Most of its architectural production consists in paper projects, prototypes, pavilions, produced in an academic environment or for specific exhibitions. The computational field therefore organizes itself around a series of individuals, of research units and architecture schools as well as around events such as exhibitions and conferences. This academic set-up has enabled the computational field to blossom away from most of the usual constraints of the construction industry. The consequence of this is an architectural production exploring various issues raised by the development of digital technologies, an exploration benefiting from much more freedom given this distance to industrial

constraints.

This freedom and explorations make the architectural production of this field a refiguration of the global computational turn in architectural design currently happening. The computational field as it has developed in the last 50 years and its production forms therefore an ideal set of designers and projects to study programming-based spatial design and the translation of architectural constraints in computational tools.

1.3. COMPUTATIONAL SPATIAL DESIGN TOOLS AS A RESEARCH TOPIC

The present research proposes to take a closer look at the digital tools in use in those experimentations and to turn them into a full research topic, in order to analyse the phenomenon through a new angle. If numerous archaeologies of the digital in architecture already exist, including the eponymous book by Greg Lynn (Lynn 2013), they consist in their majority of an assembly of emblematic projects presentations and texts by the architects and designers of the computational field. These project reviews rarely contain more than scarce details on the technical computational aspects and only few designers develop in their written production comments on their use of technical tools. Furthermore, most of the written production focuses on theoretical aspects and does not consider sociological data on the computational field in architecture. Finally, almost none of these productions offers a detailed overview of the actual use of algorithmic tools in architectural design. Only a few studies of the development of specific digital tools exist, such as an history of Form*Z (Serraino 2002), as well as a few very recent researches seemingly starting to open this field of research (Laurent et al. 2018).

The present paper proposes a method to analyse computational design tools at the architect's disposal, their development throughout the years and their technical peculiarities, including possible bias they could induce in architectural constraint translation. Six case studies will be used as a demonstration of the method's ability to highlight the role played by these algorithmic tools. Those case studies are the six answers to the Seroussi Pavilion Competition (SPC), organized in 2006-2007 by Natalie Seroussi, a Parisian gallery owner. Having a keen interest into computational design, she invited the following architectural practices to submit a design for her pavilion: biothing, DORA, EZCT Architecture & Design Research, IJP George L. Legendre, Gramazio & Kohler and Xefirotarch. As the six case studies answer the same design brief, it represents a particularly suitable opportunity to analyse the intricate relationship between architectural constraints, their translation into computational data and instructions and the programming tools used to do so.

The main objective of this research is to propose an analysis method and to discuss algorithmic design tools and the notion of technical bias in the SPC, but also to question the results of this study as part of larger considerations on the use of algorithmic tools for architectural design in recent history.

2. The Seroussi Pavilion Competition

2.1. CONTEXT AND BRIEF

The Seroussi Pavilion Competition's aim was to build a pavilion that would be housing part of Natalie Seroussi's art collection in dedicated exhibition spaces as well as living spaces. In addition to this double architectural program, the other peculiarity of the competition was the project's site, a particularly strong and specific context: the pavilion was to be built in the garden of André Bloc's home, property of Natalie Seroussi. The villa, located in Meudon, was designed and built in 1949 by the architect and engineer for himself, and the garden hosts as well two of Bloc's *sculpture-habitacles*, added in 1964-1966. A specific area of the estate was selected for the pavilion and is mentioned in the competition brief, along with comments on the specificities of the site, to be considered by the participating architectural practices. The brief also includes a detailed program (Guenoun 2007):

"The project will include an interior and an exterior space. The total inhabitable surface area of the project will be approximately 350 sqm. The interior will comprise 2 bedrooms, each with walk in closets; 1 living/dining room; 1 kitchen; 1 bathroom; 1 office (optional - can be included in one of the bedrooms); 1 toilet (outside the basement); 1 basement set up for purpose of video projections, 1 storage space for artworks between 20 and 30 sqm. Each of these spaces will, to the extent possible, include storage."

Two proposals, the first by EZCT Design & Architecture Research and the second by IJP, were selected as winners by the jury, chaired by Claude Parent. The winning proposals were not built as it was initially planned, but shortly after the competition, from June to September 2007, an exhibit was organised at the Parisian exhibition space La Maison Rouge, showcasing the six proposals.

Taking place in 2006-2007 in France, the competition was organised during a specific momentum of the computational turn in architecture. It accompanied a series of instrumental exhibitions, such as the *Architectures Non Standard* exhibition at Centre Pompidou (Migayrou 2003), the *Architecture au-delà des formes* ("Architecture Beyond Form") exhibition at the Maison de l'Architecture et de la Ville in Marseilles (Morel 2007) or, the same year, the *Scripted by Purpose* exhibition at the FUEL gallery in Philadelphia (Fornes 2007). In the previous years, starting in 2000, numerous practices were founded that went on to be major designers in the computational field, including those participating in the SPC. Those elements all hint to the fact that the competition took place at a moment where the designers taking part in the computational field at the time were building a community around these issues.

2.2. AN IDEAL CASE STUDY

The interest of the Seroussi Pavilion Competition as a case study, beyond it happening in a key momentum, also lies in the fact that the six participating practices are emblematic to the computational turn in architecture. Moreover, they are emblematic of a specific generation. The term "generation" will be used in this paper to designate successive groups of individuals taking part in the

computational turn. Those generations are characterized by their use of tools, as the use of algorithmic design tools in architectural design can be described by characterising the relation of designers and practices to those tools throughout the years. Although most of the individuals of a generation are younger than those of the previous generation and although a relationship of knowledge transmission exists between most of the individuals from two successive generations, some overlapping still exists. Five specific groups or generations can be distinguished.

The first generation (G0) is formed by isolated projects and experimentations, on primitive computational set-ups, such as the Generator project by Frazer & Price (Landau 1985). The second (G1) regroups individuals that launched the first paperless studios and similar academic research groups. Therefore, this generation constitutes an embryo of network of people experimenting with existing algorithmic tools and methods as well as theorising a new paradigm based on possible production conditions. The third (G2) is formed by designers having been taught by individuals from G1 and simultaneously exposed to various computational tools developed in other fields, such as analysis tools for engineering purposes. Their use of computational tools is characterized by an earlier and further training on programming tools available at the time. The enlargement of the network as well as the technical progress of modelling, simulation and analysis tools at the time results in a fine-tuned capacity to build their own tools and to experiment with the possibilities offered by computational design. The fourth generation (G3) displays a similar use of tools. But since it benefitted from the experience of G2 as well as from new technological progress, this generation has had the possibility to develop tools exploring computational design further, including handling more data and data of various kinds. Finally, the fifth generation (G4) corresponds to the generalisation of the recourse to programming tools, using the tools developed by G2 and G3 providing a simplified interface and therefore easier access to sophisticated algorithms. Technical bias is stronger in this generation given that the recourse to pre-existing tools partly erases the need for mastering scripting.

The Seroussi Pavilion Competition regroups a series of practices all part of the G2 group and is therefore emblematic of this generation. Furthermore, the competition represents an ideal case study since its brief offered a particularly suitable working environment to develop research on computation architectural design. The practices invited were all young, with particularly homogeneous profiles, similar dates of founding, similarities in the previous production and in the means of integrating research on computational tools into the practice, as well as fitting the relationship to tools described for G2. The lead architects of each practice also have similar trajectories, with involvement in academic environments and in teaching - on some occasions together. It is also interesting to note the presence of younger architects in the teams such as Ezio Blasetti, Roland Snooks or Dave Pigram as it also hints to a strong insertion of the SPC into the network of computational architectural research, since these architects went on to be prominent players in G3. Furthermore, despite its strong adequation as case study, the SPC has never been used as such in digital tools overviews or digital heritage studies. The only publications regarding this competition are

the exhibition catalogue (Guenoun 2007) and a few brief articles in magazines such as CREE (n°332), D'Architectures (Scoffier 2007) or A+U (n°455), either reports of the exhibition or succinct presentations of a specific proposal in an article dedicated to the practice who authored it.

3. Analysis methodology

The methodology defined here aims to gather a common set of data on each of the proposals, on four different aspects of the project: algorithmic tools/method, computational set-up, organizational chart and architectural design. The specific information surveyed are detailed in Table 1, as well as the matching data collected for each proposal. The data was collected by consulting the published documents for each project - credits, plans, renders, diagrams, code excerpts - and by conducting interviews with the leader of each practice. The items available for each proposal are indicated in table 1 as well.

Table 1. Data collected for the six Seroussi Pavilion Competition proposals.

		Practices					
		biothing	labDORA	EZCT Architecture & Design Research	IP Corporation	Gramazio & Kohler	Xefiroarch
Algorithm	Family	Formal Research	Performance-driven design	Performance-driven design	Formal Research	Fabrication-driven design	Formal Research
	Type	Attractors (agent-based; magnetic fields)	Finite Element Analysis, Particle System Optimization	Genetic Algorithm	Periodic Equation	Robotic Brick Placing	Growth
	Whole or split	Whole	Split / Not related	Split / Related	Whole	Split / Related ??	Whole ??
	Main Technical Objective	Global Shape Generation	Structural Optimisation	Light Optimisation	Global Shape Generation	Detailed Shape Generation	Global Shape Generation
	Secondary Technical Objectives	/	Global Shape Generation, Detailed Shape Generation	Structural Optimisation, Global Shape Generation, Detailed Shape Generation	Mathematical Sobriety	Fabrication files generation	/
	Output	"Flower" Shells (Roofing)	Shell Shape and Structural Elements	Main Shell Shape, Structural Pattern for Surface Subdivision	Modules	Wall Shape and Bricks Placement	?
	Significant Variables	Position of Attractors	Double Shell Structure	Shape of retrieved blocks	Periodic Equation / Cylinder	Robotic Placing Constraint	?
Technical Set Up	Software	Rhinoceros + FlowerPower	Rhinoceros, Finite Element Analysis Software	Rhinoceros, Mathematica, Radiance, Maya, Blender, VTK, Polytrans, Geffem++, 3Dmax, Vray, EO, Cata	MathCAD	Maya	?
	Programming Language	C#	C#	Python, C++, Wolfram	Mathematics	MEL	?
	Interface type	Plug-in with slider parameters	/	Scripting	Scripting	Scripting	?
	Graphic Representation Tool for Basic Geometry Visualisation	Rhinoceros	Rhinoceros	Rhinoceros	AutoCAD	Maya	?
	Final Output Type	3D + 2D Drawings	2D Drawings	3D + 2D Drawings	2D Drawings	3D + 2D Drawings + Fabrication File	3D + 2D Drawings
Chart	Date of Office Creation	2001	2001	2000	2000	2003	2001
	Number of people (Team + Consultants)	7 + 1	17 + 7	11	10	12	10
	Background of principal	Architecture	Architecture	Architecture	Architecture	Architecture	Architecture
	Background of team	Architecture, Computer Science	Architecture	Architecture, Computer Science, Mathematics, Daylight Modelling, Structural Engineering, Visual Rendering	Architecture	Architecture	Architecture
Architectural Design	Background of Consultants	Mathematics, Visual Rendering	Architecture, Computational Design, Structural and Environmental Design	/	Landscape Design	Structural Engineering	/
	Drawn Architectural Design Independent of the Algorithmic Output	Yes (plan)*	Yes (structural principle)	Yes (plan)*	Yes (plan)	Yes (plan)	
	Site-Related Items (verbal mention, written mention, site plan, sculptures present on drawings)	2	2	4	3	3	4
Available documents	Brief compliance (program)	Partial	No	Partial	Yes	Partial	Partial
	Site Plan	Y	Y	X	Y	Y	Y
	Ground Plan	Y	X	Y	Y	Y	Y
	Drawings (Sections, Renders)	Y	Y	Y	Y	Y	Y
	Code	X	X	X	Y	X	X
	Diagram/Illustration of algorithmic method	Y	Y	Y	Y	X	Y
	Credits	Y	Y	Y	Y	Y	Y
	Interviews	Y	Y	Y (informal)	Y	Y	X

4. Discussion

4.1. BEYOND TECHNICAL BIAS, THE ISSUE OF TECHNICAL LIMIT

One of the characteristics of this computational generation is high awareness of potential biases contained in the algorithmic methods and digital tools relied on. This is also apparent for the practices taking part in the SPC in the comments made on the use of tools and on the development of the algorithms for the competition. The interviews also highlight a common background and convergences in the discovery and learning of computational tools, often in a learning environment with strong intellectual emulation and exposure to disciplines other than architecture. Benefitting from this training and from the feedback of previous generations, they have a fine-tuned mastery of programming tools and therefore an ability to fully explore their potential in shape generation, constraints assimilation or performance optimisation. But each of the proposals dealt mainly with one of these aspects, as the categories of design in line 1 of table 1 highlight.

The variety of software used (Table 1 Line 11) is a reminder of the technical complexity in play at the time to implement the algorithms, ensure bridges between specific software and different file formats, plot geometries and so on. The documents published by EZCT include a chart of the different software and file format their algorithm for the competition relied on, including 12 software and 5 file formats. Although it is the only team that detailed the technical set-up this way in written documents, other interviews point to a same scale density.

Considering these two aspects, the issue at stakes in terms of technical tools and their use appears to be the technical limit existing at the time and how to handle it, rather than potential biases of specific algorithmic methods. The selection of one exploration direction at a time is a direct consequence of this. Each of the proposal illustrates a different strategy to manage this limit and produce an architectural answer to the brief.

For the Gramazio & Kohler proposal, the constitution of a set of specific fabrication constraints enabled an architectural design developed based on those, making it an example of fabrication-driven design.

EZCT and DORA both designed a performance-driven algorithm, but the extreme difficulty at the time to implement such algorithm in its entirety led them to explore it in a different way. If EZCT chose to complete the implementation of their light-optimization algorithm, thus handling the most complex technical set-up, DORA established the possibility of such an algorithm by defining the workflow and testing parts of it, but then moved on to a reflexion on architectural reference and how to integrate it in an algorithmic project design.

As expressed during the interview, what drove the design of IJP proposal appears to be an attempt both to remain faithful to a single mathematical idea - as has been seen in most of the other projects designed by the office, such as the Henderson Waves (Hwang 2006) - and to answer as closely as possible to the architectural brief. The idea of developing a project around a single mathematical idea pairs with keeping the problem of technical limits as well as potential technical bias afar and enabling to focus on the development of the architectural design.

Xefirotarch and biothing have in common the exploration of a predefined aesthetic and spatial potential, in the sense that the architecture of their proposal is a variation based on the shapes produced by the algorithm. In both cases, the developed algorithm offers a specific formal vocabulary, that is then adapted to the architectural proposal.

During the interview with biothing, the notion of technical limit was stressed through the description of a gap still existing in architectural algorithmic designed, in opposition to the often-described goal of uniting every step of the design by means of digital tools. This gap could be described as the intervention of architectural decision making in order to guide the use that is made of algorithmic tools. The articulation between those two elements is critical both in the description of how designers resort to computational tools and in the treatment of the technical limit.

4.2. THE PLACE OF ARCHITECTURAL EXPERTISE IN ALGORITHMIC DESIGN

The design process for the proposals all show a stage at which architectural elements of the proposal were not generated by the computer but conceived and drawn by the team. In several cases, it is the plan of the proposal that was drawn upstream (Table 1 Line 21). At that point, the algorithm already being in development, the formal results that were generated by it were evidently considered while drawing the plan. But the plan was drawn without recourse to computational tools. Afterwards, in a second phase, either the plan was fed as input to the algorithm, either a series of shapes was generated and then plugged onto the previously drawn plan, to create the architectural proposal itself.

Although the issue of translation of architectural constraints and decision-making into algorithmic language is at the core of computational design, a significant part of decision-making that is relevant to space design has in the case of the Seroussi Pavilion proposals taken place in part separately. The interlocking of algorithmic development in order to obtain specific geometries and of external architectural decision making therefore appears to be a characteristic of this generation of experimentations as well.

The architectural brief and specifically the program of the pavilion as highlighted in the competition brief was in general not fully respected, or even in the case of DORA, not respected at all (Table 1 Line 23). This disregard is explained by the at the time rare opportunity offered by the competition to experiment with computational design and each practice favoured the exploration of the formal and architectural possibilities that could come out of it. But despite this disregard, deep architectural concern shows in each proposal. Notably, the importance of the building site, hosting André Bloc's villa and more importantly his *sculptures-habitacles*, was mentioned several times. The visual and historical strength of these works were mentioned by most of the architects, and they appear on most drawings (see Table 1 Lines 22, 24, 25). The EZCT proposal is particularly interesting concerning this, as the shape of the retrieved blocks in the initial genetic algorithm, informing the shape of the final pavilion, seem a direct formal reference to the surrounding sculptures.

Beyond the tension between the exploration of computational tools and the design of an architectural proposal, the ongoing changes in the profession are also apparent in this analysis (Table 1 Lines 17 to 20). The different teams present both traditional players, such as a leading architect and engineering consultancies, but also other players specific to the development of computational design, such as software designers (biothing) or a daylight modelling specialist (EZCT). Furthermore, the leading architects all have developed skills specific to designing with programming tools. The professional background and set-up of the teams for the competition is therefore an interesting example of how transitioning to computational design might happen on the professional level.

5. Conclusion: Paradigmatic consistency & technical evolution

Several comments made by the architects on the competition during the interviews referred to their current practice - in opposition to their practice at the time - and highlight how the issues at play in architectural computational design have developed at the time and how they transformed until now. As computational tools develop and the technical limit retreats, both more and more data and new types of data can be considered. Tools that are being developed currently (Salim & Haque 2015) (Sanchez 2013) as well as the evolution of the general discourse on computational design (de Rycke et al. 2018) hint to the fact that computational tools currently develop towards data not only in the domain of performance analysis, but as well elements such as aesthetical choice (Brown & Mueller 2017) or data gathered through massive participation to online platforms. All these issues can although be summarized into on single question, which is the question of automated design. Ultimately, it is this same paradigm that leads all computational experimentation, with the same theoretical background for most designers in the computational field. The evolution of architectural proposals throughout the last 45 years is due in part to the evolution of the tools themselves, more than to the evolution of the issues architects and designers deal with, a relation that can be shown through a historical study of computational tools, such as this research has suggested.

In conclusion, the research presented in this paper attempts, through the elaboration of an analysis method for architectural design integrating programming tools and through the outline of a possible taxonomy for computational architecture, to document the existing digital heritage in a new approach. The application of this method to a specific case study demonstrates its ability to lay out new socio-historical data for a better understanding of the context of emergence of programming tools in space design and of their influence on the resulting architectural objects, in order to contribute to a history of computational tools in architecture.

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