Archnet-IJAR: International Journal of Architectural Research
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INFLUENCE OF PARAMETRIC TOOLS ON THE COMPLEXITY OF ARCHITECTURAL DESIGN IN EVERYDAY WORK OF SME'S

Adeline Stals; Sylvie Jancart; Catherine Elsen

Keywords

Parametric modeling; complexity; SME's

Abstract

Digital design tools and notably parametric ones have generated profound modifications of the architectural practice. In line with this evolution, technological and formal changes at the scale of architectural artifacts are underway, leading to a shift especially in regard of how architects deal on an everyday basis with CAD and morphological complexities. Big offices, thanks to their human and financial resources, have faced these difficulties and pushed the limits of their architectural projects. Little is known, however, about how smaller offices, accounting for the largest part of the European market, did adapt to these profound evolutions. Going through the results of a large-scale online survey, this paper analyzes the Belgian case regrouping mostly small and medium offices. The contribution discusses the meaning of parametric design for architects and reflects particularly on how architects do or do not implement these new digital tools in their everyday workflows. The results eventually shed light on the fact that parametric tools have the potential to free the creativity of SME's and moreover unveil how these tools might overcome some of the current complexities of the daily architectural practice.

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*Adeline Stals**
LNA, Faculty of Architecture, University of Liège, Belgium;
Sylvie Jancart
LNA, Faculty of Architecture, University of Liège, Belgium;
Catherine Elsen
LUCID, Faculty of Applied Sciences, University of Liège, Belgium.

**Corresponding Author's email address: adeline.stals@uliege.be*

INTRODUCTION

Digital design tools are no longer a substitute for hand-drawing tools. Beyond the possibility of innovating in terms of architectural morphology, those tools actually induce a cultural change. This change takes place technically and humanly, as both the ways of practicing architecture and its disciplinary definition have changed in recent decades (Picon & Razavi, 2011).

The evolution of technologies on various levels (design, calculation, manufacturing) has certainly allowed the emergence of new profitable constructive possibilities, but has also paved the way for renewed levels of complexities inside the architectural workplaces. A research by Chase and Murty (2000) mentions in that regard two notions of complexity. They name the first one, the design complexity, relating to the appearance of the designed object, also discussed by Oxman and Gu (2015, p. 477) under the term morphological complexity: “among its forms of influence, parametric design has affected the topological and formal characteristics of designs produced in diverse design fields such as architecture, industrial design and fashion design.” The second complexity, CAD complexity, is actually what Chase and Murty develop in their paper. They define CAD complexity in an architectural context, relating to the use of CAD functions applied to both organization and production of the completed model. This opens discussions about the evolution of morphological and tools’ complexity, and how there are actually perceived by the day-to-day practitioners.

These evolutions, and notably these emerging forms of complexity, have been faced by big offices thanks to their resources and large teams of software engineers, enabling them to train their teams to these renewed workflows. Research studies have been generally performed within these large offices whose parametric practices are recognized, setting aside the experimental applications of parametric tools inside small and medium architectural firms (SME’s)[1]. Yet, SMEs represent 77.7% of the Belgian offices in 2016 and moreover an estimate of 99% in Europe in 2014 (Architects’ Council of Europe, 2015). Questioning their day-to-day digital practices is therefore crucial, considering the representativeness of offices of these sizes. We therefore wonder: have parametric tools influenced the complexity of SME’s everyday architectural design? And if yes, in which way?

The goal of this paper is to discuss how designers have experienced these technological and formal changes. In order to do so, we collected empirical data through a large-scale online survey that structured knowledge about Belgian architects’ and architectural engineers’ everyday practice.

The paper first goes through a review of complexity and its evolution through history of architecture. This evolution contextualizes the emergence of parametric modeling and highlights our research gap. We go further with technical details and the methodology used to design and distribute the online survey. The summary of the main results is later divided in three parts: firstly we review the state of digital and parametric tools’ uses in everyday practices, then these results are completed by an analysis of Belgian designers’ interest in and understanding of parametric tools. We eventually dig deeper into the impact of digital and parametric tools on architectural practices. A discussion about the results addresses the perception of digital tools and the understanding of parametric ones. We also discuss where the complexity in the daily work lies in SME’s.

[1] In a report written by the Walloon Region (Direction générale de l'Economie et de l'Emploi, General Direction of Economy and Employment) defining the term *SMEs* in the European sense, a society of less than 10 employees is called *micro entreprise*. Taking into account the particularity of the architectural market compared to the economic market in general, we refer to these small offices as SMEs in this research.

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THEORETICAL EVOLUTION OF MORPHOLOGICAL COMPLEXITY THROUGH HISTORY OF ARCHITECTURE

This section deepens the notion of complexity in architecture in light of three consecutive eras of architectural history: first when the physical experimentation was considered the primary tool for dealing with such complexity, second at the very beginning of digital architecture and, third, in regard of the current use of digital design tools. We close this section by clarifying some confusions that may persist in the field of parametric design, especially when it comes to the multiple definitions of the concept itself and the categorization of well-known commercial software in each of its sub-categories.

Morphogenesis through experimentation

In the past, understanding and controlling morphogenesis of structures, often inspired by nature, usually relied on empirical, trial/error methodologies requiring complex physical prototyping and experimental settings. Architects and engineers such as Antonio Gaudi, Heinz Isler or Frei Otto conducted such studies in order to progressively refine their funicular, shell or lightweight tensile and membrane structures (Stals, Elsen, Jancart, Delvaux, 2015). One can admit that these architectures expressed a certain kind of simplicity both on an aesthetic and structural level, given the intrinsic coherency of their formation process. However those experimental processes still generated complexity in terms of mathematical description of the shape, not yet mastered at that time. Moreover, those mechanically constrained generated shapes, chosen because they ensured some structural coherence, also limited the architects in the diversity of exploitable morphologies.

First step into the digital era

In the late eighties, computer aided design machines speeded up the drafting and modifying process, leaving the rest of design steps mostly unchanged. CAD, first intended as a medium for production, was perceived as difficult to use in the early stages of the design process where the priority should remain creativity rather than precision (Guidera, 2011). The increasing complexity of architecture nevertheless pushed architects to find tools adapted to express their ideas. Some architects focused their research on how to model their ideas, other have been interested in how to communicate them and notably through immersive virtual environments (Abu Alatta & Freewan, 2017).

In the early 21st century, a new generation of tools (such as parametric software) started to emerge and more deeply impacted the design process. Generative design approaches, among them, resulted from the need for renewed strategies to facilitate the exploration of alternative solutions in design, considering computers as an opportunity to achieve unexpected but viable solutions, rather than a thread. Kolarevic (2003) used the term “digital morphogenesis” to refer to design processes in which digital media is not used for representation but as a generative tool for the derivation of form and its transformation.

However, the inventory of projects designed at that time indicates that the complexity of these shapes did put some distance between the ideas on screen and their feasibility. Most of the software used at those early times, initially supposed to simplify the design process, rather generated multiple levels of complexity. Based on what Picon appointed as *disruptions* (2010), we sum up these renewed complexity levels in three main categories, partly explaining from our point of view why lots of these complex shapes remained at a virtual stage (Stals, Elsen, Jancart, 2016). One complexity takes place between morphology and structure, the digital approach rather encouraging morphological audacity at the expense of structural coherency and rationality. Another complexity appears at the interface of multidisciplinary skills and knowledge of the design process, tarnishing the already intricate collaborative process by multiple confusions and misunderstandings. The last identified complexity operates at a scale and tectonic level of the project. The evolution of digital manufacturing tools has enabled the development of new building materials and especially to personalized prefabrication, sometimes confusing the distinction between primary and secondary elements of buildings, for instance. All these complexities, we argue, lead to tensions between architectural desires and practical, technological feasibility.

Digital architecture nowadays

Lately, more and more of these complex shapes have been built. Projects such as the Pompidou Center by Shigeru Ban, or the Louis Vuitton Foundation by Frank Gehry have indeed been erected, demonstrating that larger companies (generally taking advantage of generous budgets) have found ways to work around those levels of complexity. The attitudes of architects are consequently slowly evolving, some of them realizing that the introduction of digital tools into the design process might enable more than simply representing and processing information. Those architects, depending on their capacity of action, are therefore ready to explore how these tools might contribute to the development of innovative morphologies, better adapted to their expectations and creativity (Terzidis, 2004). By doing so, they still have to address the above-mentioned complexities, and to do so they tend to develop specific protocols and strategies. These protocols and strategies have been firstly studied in the context of large, internationally recognized architectural offices. Shelden (2002) for instance has questioned the representation and constructability of Gehry's Architecture with respect to parametric use. Specifically on parametric tools, we can mention the research of de Boissieu (2013), again conducted in large offices whose practices are recognized, showing what characterizes the architects' cognitive operations when using parametric tools.

While large architectural firms have thus developed their own research and development teams, and even their own proprietary software, little is known about the strategies developed by small and medium architectural firms. This gap is even more relevant when looking at parametric design in architecture. Following up existing literature on this topic, the only study paving the way on how small agencies deal with digital tools was indeed carried out in Austria and England but could not be concluded due to lack of architect's participation (Dokonal & Knight, 2008). More specifically in Belgium, the last study about the use of design tools by architects was conducted in 2008 (Weytjens, Verbeeck, & Verdonck, 2009). The goal of this survey, mainly addressed to the North part of the country, was to assess the impact of different type of design support tools (DSTs) through the decision making process. This research was thus not specifically focusing on the role of parametric tools in architectural practices, nor did it tackle the confusion that might occur between the various interpretations of the terms in this field. It rather classified six types of design tools according to the role they played all along the design process: based tools, communication tools, modeling tools, presentation tools, structuring tools and evaluation & analysis tools.

In parallel, some studies investigated parametric through experimentations in an academic environment. For example, Guidera (2011) analyze parametric as an exploratory design medium for novice students, shedding light on the fact that formal exploration is more frequent than expected. Some studies, on the other hand, develop some interest for parametric processes in architectural practices but do not identify their field study. Peters and Whitehead (2008) for instance evoke in particular the interest of parametric to link parameters and therefore to give more coherency to the project, but without supporting these affirmations by concrete field research. Table 1 sums up this panel of previous researches and highlights (in the grey column) the little interest for SME's practices in general, and for the use of parametric tools in particular.

Table 1. A look into researches done about digital and parametric practices. In regard of each column (i.e. each category of observed participants) the minus (-) and plus (+) indicate how familiar those participants are with the technology, according to the respective authors (Source: Author, 2018).

Authors	**Years**	**Topic**	**Country of the research**	**Students**		**SMEs**		**Large offices**		**Offices with no specific size**	
				-	**+**	**-**	**+**	**-**	**+**	**-**	**+**
Chien, Yeh	2012	Creative design process in parametric design	Unspecified (country of authors : Taiwan)								x
de Boissieu	2013	Parametric modeling in architectural design: characterization of cognitive operations	France	x					x		
Dilys, Burry	2010	State-of-the-art of parametric modeling and analysis of degree of software openness	Australia								
Dokonal, Knight	2008	State of digital architectural design	UK, Austria	x		Irrelevant					
Guidera	2011	Conceptual design, exploration using parametric computing	USA	x							
Peters, Whitehead	2008	Discussion on geometry, shape, complexity with an algorithmic approach	UK						x		
Shelden	2002	Digital surface representation and the constructability of Gehry's Architecture	USA						x		
Weytjens and al.	2008	Classification and use of design tools: the roles of tools in the architectural design process	Belgium (Flanders region only)							Irrelevant	

In addition to this scarce quantity of research conducted in SME's, we observed during some focus groups that architects were still confused about terminology related in particular to BIM and parametric fields (Stals, Jancart, & Elsen, 2018). The following section summarizes the results and clarifies certain terms.

The various understanding of "parametric design"

Confusions actually exist in regard of what can be called "parametric design" and how one can distinguish between the various commercial software offered to architects. We will therefore first define what this paper refer to as parametric design and confront it with the notion of Building Information Modeling (BIM). We will then go deeper into the explanation of parametric modeling.

To understand the fundamental meaning of *parametric design* ((a) – see Figure 1 below), we should go back to its very first steps and more specifically to the formal research carried out by Antonio Gaudi, especially for the generation of funicular curvature vaults of the Sagrada Familia. Parametric design was once analog and this research can effectively be considered as part of the very first reflections that led to the current digital parametric design. Considering this seminal work, parametric design can therefore be defined as a design methodology that enables, among other things, to generate forms from the exploitation and manipulation of a large amount of environmental, acoustic, structural, social or urban data taken over as 'parameters'.

This early version of a definition can be completed by the following statement of Oxman and Gu (2015, p.479): *“the interest of the practice is a passage from drawing of a singular object to the construction of a design process. In the parametric design process, once the rules are implemented, an unlimited number of design alternatives can be generated in parallel.”* From basic *parametric design* there is consequently a shift towards *parametric design process*, characterized by three principles according to Woodbury (2010):

1. Designers develop rules and define their logical relationships while creating 3D visualization models;

2. Designers can modify their model at any time;

3. Design alternatives can be developed in parallel at any stage of the process.

Recent developments in computer science have seen the emergence of two modeling processes, both of which have gained recognition while sometimes inducing certain forms of confusion (Figure 1): parametric modeling (b) on one hand, and BIM (Building Information Modeling) (c) on the other hand. These two terms, commonly used, overlap and are sometimes misused. Indeed, these two modeling logics share the same goal of integrating various data into the architectural project. While in the BIM process, data integration rhymes with adding an additional layer of information to some geometric model, confining the data to complementary static elements, the case of parametric modeling directly integrates the data in a process of morphogenesis, and can therefore be referred to as *computational design*.

Looking now at these computational design processes, two additional types of modeling emerge. They distinguish mainly in terms of selected modelers. In the context of parametric modeling software (e) such as Rhinoceros© or Digital Project©, the designer has to link parameters and dimensions to pre-programmed geometric constraints. For example, to create a circle in Rhinoceros©, the consumer sets up the preprogrammed "circle" function and provides it with parameters (center position and radius). On the other hand, in algorithmic modeling software (f), such as GenerativeComponents© or Grasshopper©, the designer is invited to manipulate a textual or visual programming language (similar to a computer programming code) that enables him/her to go beyond the limits of the user interface (Leach, 2014). In the remainder of this article, although the term "parametric" is retained because of its common use in architectural research, we will focus only on *algorithmic modeling software* and more specifically on those with a visual programming interface. Indeed, looking into the small community of early adopters, this mode of visual programming seems preferred by the architects, propelling Grasshopper© to the rank of the most widely used parametric software in general (Cichocka, Browne, & Rodriguez, 2017) and also in Belgium, proportionally speaking (Stals, Elsen, Jancart, 2017).

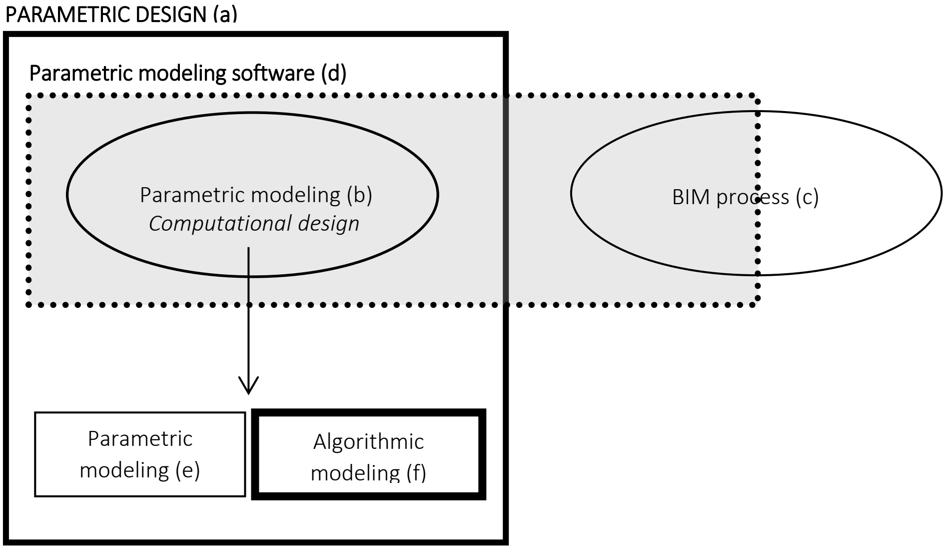

Figure 1. Relation between terms in the field of parametric design and focus on "algorithmic modeling" referred to as "parametric modeling" in the remainder of this paper (Source: Author, 2018).

Consequently, and in order to summarize what we mean by parametric modeling in this paper, we rely on the words of Turrin and his colleagues (Turrin et al., 2015, p. 5):

"Parametric modelling allows representing geometric entities having editable attributes, and relationships by means of associations. Attributes can be expressed by independent values, which act as input to the model; their eventual variations generate different solutions of the model. Associations allow for processing the data across the related geometric entities; this means the different solutions of the model are generated while respecting the consistency of pre-established relations among geometric entities".

To complete this semantic review, one has to acknowledge the fact that some parametric modeling software (a) moreover support BIM processes (c), just as efficiently as they support parametric modeling (b) (see Figure 2). To differentiate between these two modeling logics, we therefore refer to the writings and examples provided by Janssen and his colleague (Janssen, 2016; Janssen & Stouffs, 2015). These authors categorize these two types of parametric modeling according to the type of iteration each software supports. To start with, they refer the term "associative modeling" to BIM systems such as Graphisoft ArchiCAD© and Autodesk Revit©. This type of modeling is characterized by the simplest type of iteration: single-operation, which applies the same operation simultaneously over multiple geometric entities, limiting the ability to automate the model-building process. For instance, if the input of an 'extrude' operation consists of a list of polygons, then the node may iterate over the list and extrude each polygon in turn. In contrast, the authors associate "data flow and procedural modeling" to parametric modeling, used for software such as McNeel Grasshopper© or Autodesk Dynamo© for instance. In this case, the software rely on *implicit* multi-operation iteration which is the most powerful. Working with data structures, it therefore performs more complex types of data matching. For example, if the extrusion distances are also provided as a list, the operation may iterate over different lists. The procedural modeling is therefore defined as "supporting *explicit* multi-operation iteration". Authors eventually close the subject by listing "object modeling", which refers to software supporting no kind of iteration, such as SketchUp©. This type of software does not generate confusion with other classifications because they are generally not seen as parametric modeling software by architects.

ArchNet IJAR
International Journal of Architectural Research

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Archnet-IJAR, Volume X - Issue X - Month YYYY - (xx-xx) – Regular Section

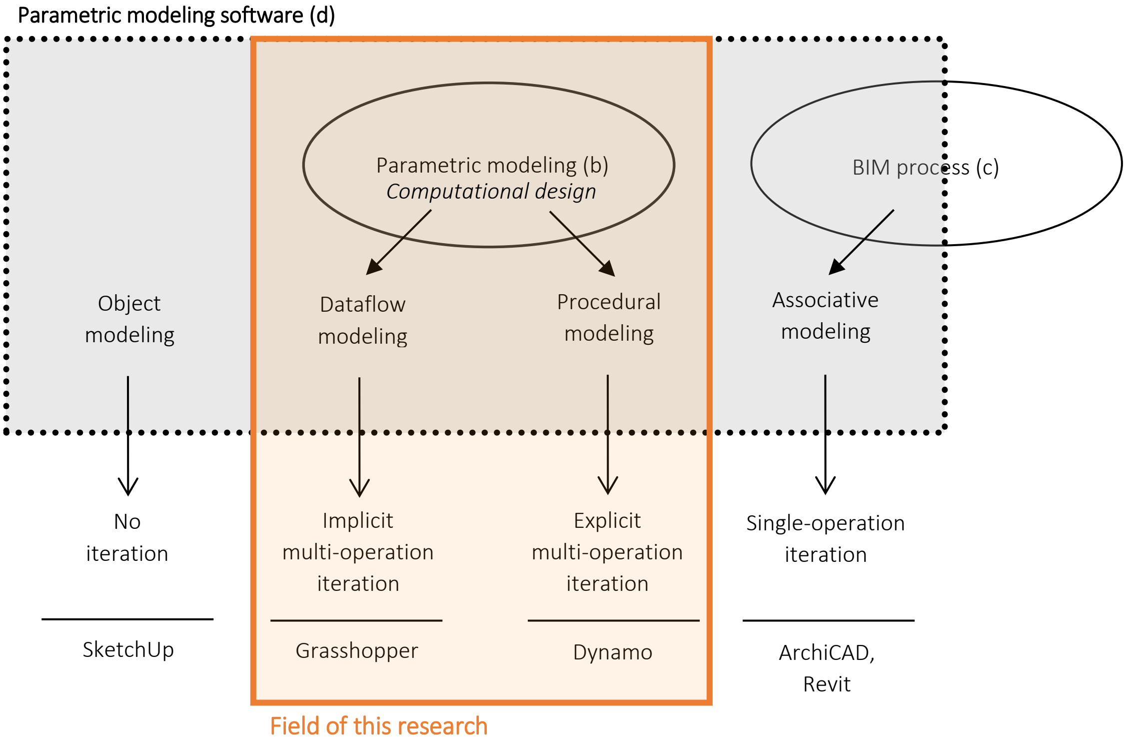

Figure 2. Types of parametric modeling software, on basis of Janssen and his colleagues' work (2016) (Source: Author, 2018).

RESEARCH GAP

The need to clarify these multiple definitions and categories is related to the fact that no consensus has been reached, neither among the community of practitioners nor among the scientific community. Yet, digital tools, and specifically parametric ones, are nowadays recognized for their potential to lead to new complex, non-standard pieces of architecture. Lots of researchers have focused on large offices' strategies, but little is known about how small and medium architectural offices do deal with such digital tools.

Considering this current state of knowledge, this paper will therefore address three main research questions:

- How is the parametric modeling perceived? Do architects express interest for new software such as parametric ones?
- Considering the use of digital tools nowadays, how do architects specifically use parametric tools?
- What influence do parametric tools have on the design process? Where does the day-to-day complexity hide in regard of those parametric tools?

In line with these questions, the next section reports findings collected from a large-scale survey identifying (i) the current situation of Belgian offices and more specifically the challenges small and medium offices face in dealing with digital tools during their design processes, and (ii) their perception of complexity all along these processes.

PRACTICAL LOOK INTO BELGIAN PRACTICES

Methodology

To question the digital tools architects use and their parametric knowledge, we decided to interview the Belgian community and its large proportion of small and medium architectural offices. To do so, we contacted about 13.000 architects or architectural engineers registered in the three different regional Architects Associations, out of the 14.482 members registered in 2016 (Ordre des Architectes, 2016). Regarding the large amount of people to reach, we used an online-based survey strategy in order to explore the previous research questions. The following sections aim at describing the methodology to rigorously build and analyze this survey.

The questionnaire was built around three main sections: demographic data, digital tools and parametric practice. The first part aimed at collecting the participants' demographic data in order to contextualize each profile. Ten questions were formulated (1 open-ended question, 7 semi-open questions and 2 closed-ended questions) and mainly related to the participants' gender, age, background, expertise, main day-to-day tasks and size of firm. The second section questioned designers' digital culture, the digital tools they used on a daily basis, their feelings about those digital tools and the impact those digital tools have on the architectural design process, from their point of view. This section contained 26 questions with 6 open-ended questions, 10 semi-open questions and 10 closed-ended questions. In this paper, the analysis of this section will solely focus on the participants' knowledge and use of parametric tools. Other results specifically focusing on the role of digital tools in regard of multidisciplinary work for instance have been published elsewhere (Stals, Jancart, Elsen, 2016). The concluding section investigated parametric design and tools, whose results will be the chore of this paper. This section was structured around 9 questions (1 open-ended question, 1 semi-open question and 7 closed-ended questions), discussing the understanding of the concept and the impact on practice. This section asked, for example, to "rank according to your priority the difficulties encountered when using parametric tools."; it also investigated whether designers felt concerned by the arrival of new parametric design tools or in what time period they planned to train themselves to parametric tools use. The whole survey is available on demand (please contact authors).

The questionnaire was tested with a first round of three architects, which enabled us to clarify the meaning of some statements, to adapt some fixed-alternatives answers and to test the time needed to complete the questionnaire rigorously.

After this test-survey, we concluded that if a completed survey fulfilled one of the following criteria, it was considered unusable and therefore was not included in the next steps of our research:

- The survey was completed far too quickly and therefore could not have been taken seriously. The test-survey round demonstrated that the 15 minutes boundary was the right limit;

- Only the first section of the survey was completed (the other two completely ignored), and therefore offered no data about neither digital nor parametric design/tools. This means that some surveys, where only a few questions have been dismissed, are still considered as valuable (in that case, a "no answer" or NA notation appears in regard to the few dismissed questions);

- Regarding the size of the firm, we put aside participants working in structures of more than 100 people. These people, the "background" and "main tasks" sections reveal, are mostly architects working as academics only or included in larger, contractor structures, which are out of the scope of our research.

The analysis of the data mostly concentrates on quantitative results treated in order to delineate general trends, supported by specific statistical tests and qualitative data to more closely look at some of these trends.

Sample description

For this study, over 700 responses were collected and 572 answers were eventually selected for analysis after cleaning the data. This amount represents 4.1% of the architects registered in the three different regional Architects Associations. The female-male observed ratio is close to the one collected through another survey conducted in 2014 by the Architects' Council of Europe (73.0% of male architects at that time)(Architects' Council of Europe, 2015). In our case, 72.9% of the surveys have been answered by men and 26.8% by women (while 2 people did prefer not to answer), indicating that the current sample is sufficiently representative of the Belgian community. Our survey displays 49.3% of the participants under 40 years old, confirming the relative youth of the population as already observed by the 2014 survey. In regard of expertise, 32.9% of the respondents are practicing their main occupation for less than 10 years, 27.3% are practicing it for 10 to 20 years and 38.3% for more than 20 years (Figure 3 – 1.5% did not answer). Regarding their professional situation, 52.6% of the respondents are isolated, independent architects (working on their behalf), 22.0% are independent architects working for some collaborator, 5.5% are employees, while 3.9% are architectural engineers and 2.6% are teachers (other participants distribute among other occupations). Throughout this paper, we will refer to the participants as "designers", generally speaking.

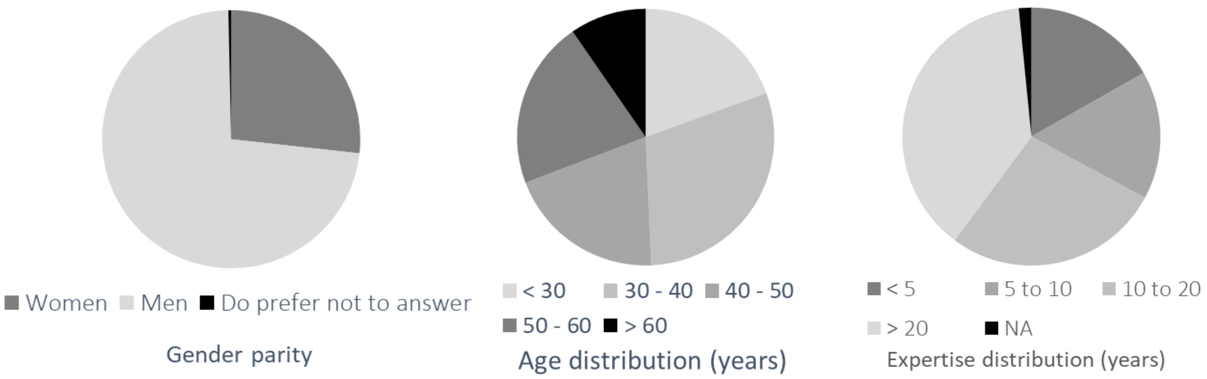

Figure 3. Distribution of gender, age and expertise among Belgian architects (Source: Author, 2018).

The 2014 European survey moreover showed that the amount of medium-sized offices was continuously decreasing, in favor of smaller structures: at the time being, already 74% of European offices counted only 1 person. Table 2 demonstrates the relevance of our Belgian case in that regard, since 42.7% of the respondents are indeed working in a firm of only one or two people. Furthermore, almost 80% of the participants are working in a structure smaller than 10 people (see shaded cells in Table 2). This trend also justifies why the paper intensively focuses on understanding the daily routines of small and medium architectural offices, not deeply studied by researchers and yet constituting the larger part of the professional practice.

Table 2. Size distribution of firms in Belgium, according to our survey (Source: Author, 2018).

Size of firms (number of people)	**1 to 2**	3 to 5	6 to 10	10 to 20	20 to 50	50 to 100	NA
Percentage	**42.7%**	22.6%	12.4%	11.9%	5.2%	3.7%	1.6 %

Results

Study of digital and parametric tools in architectural design

We organize the results of the survey under three major topics, enabling comparisons between digital and parametric tools. We begin by describing the use of digital tools in general compared to the practice and use of parametric tools. We go further by detailing the meaning of the word "parametric", as understood by the Belgian designers, in order to delineate the complexity hidden behind this type of digital tools (in terms of multiple definitions; of existing confusions between various commercial packages). We eventually contrast the different impacts digital tools and parametric tools have on architectural practice, and notably in regard of the diversity of shapes designed. This comparison highlights the generated complexities induced or mastered by each kind of tool.

State of digital and parametric practices

To complete the current state of knowledge about digital and parametric practices (Shelden, 2002; Woodbury, 2010; de Boissieu, 2013), we report in this section the results of current Belgian practice. Our results first show that 76.9% of the participants indeed use digital tools during the design phase. This percentage confirms that our research meets the current day-to-day working realities. We still have to underline that the use of digital technologies decreases as the age increases, 17.8% of the designers aged 55 and more indeed declaring not using any digital tool, while only 5.9% younger than 55 years old stating not using digital tools.

Additionally, designers were questioned about digital tools they use: "*In what way do you use 2D, 3D or parametric software listed below? (Please specify if it is 2D or 3D use when you use them. Multiple choices possible)".* Figure 4, in that regard, shows that designers using design tools just for 2D drawing mainly use AutoCAD© (56.2%), followed by Vectorworks© (19.6%) and ArchiCAD© (14.8%). ArchiCAD© is also used as a 3D support tool (22.8%) but Sketchup© remains the reference for 3D modeling in architectural design, at least for 52.3% of the users. Parametric software such as Grasshopper©, Generative Component©, Vasari© or Digital Project©, as Figure 4 demonstrates, are either totally or largely unknown by the Belgian sample.

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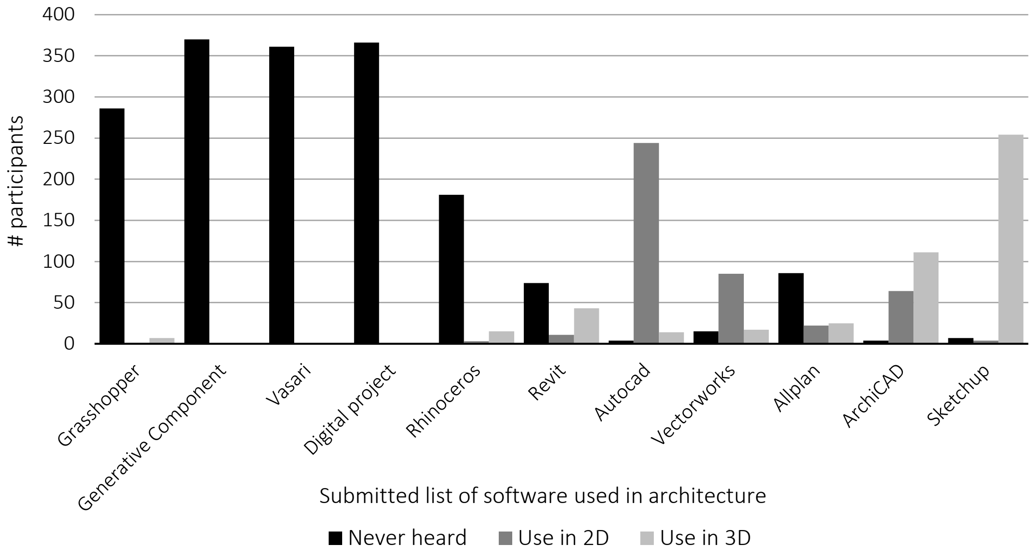


Figure 4. Use of digital tools in Belgian architectural practice (Source: Author, 2018).

Yet, 12.5% of the participants state using parametric tools on a regular basis. Out of these participants, those who do engineering calculations are the most frequent users of parametric software (Fig. 5), followed by those who practice 3D modeling (18.6%) and those who do designs of public buildings (17.8%), i.e. larger projects. The design of residential projects comes in last (11.9%), although this type of project still represents 37.4% of the tasks generally undertaken by the Belgian architects interviewed. These figures validate the fact that designers carrying out residential projects (generally corresponding to small to medium-sized buildings) do not feel concerned by the arrival of parametric design tools, leaving them to larger, more complex projects. The following quotes about architects supposedly using parametric tools, according to some participants, confirm the results mentioned above: *“Zaha Hadid and all the star architects”, “this type of architecture is confined to projects "headlights" and very amply funded”.*

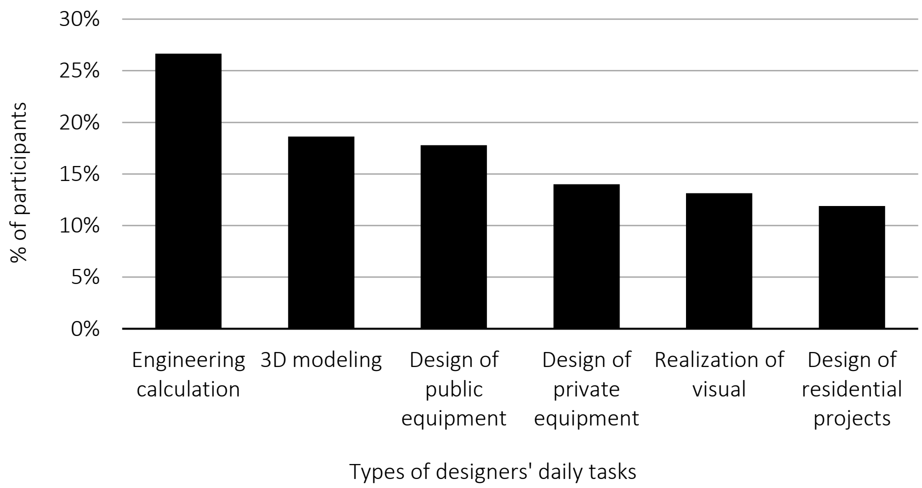


Figure 5. Types of tasks and respective use (in % of respondents) of parametric tools (Source: Author, 2018).

Interest and understanding of parametric tools

First of all, resulting from the following question "*What evokes for you the term "parametric modeling" in architecture?",* our study shows that more than half of all the respondents (51.5%, N=369) have never heard of the term "parametric modeling". Concerning the evocation of this term, there is a slight growing tendency to better understand parametric modeling with the office growing in size. The same tendency is observed in Figure 6 in regard of the interest rate for parametric tools. To validate these trends, we have tested whether "yes" and "no" answers were equally distributed by size of offices. To do so, we used the Mann-Whitney U statistical test which rejects, in a highly significant way, the assumption that "yes" and "no" are equally distributed regardless of the size of the firms (p-value = 7.293/10000). Therefore, we can state that, at least at the time being, the smaller the offices, the less interest they have in digital tools such as parametric ones. Our results moreover underline that globally speaking only 14.4% of the respondents state "being concerned" about the arrival of these parametric tools on the market, leaving 38.6% of non-concerned participants and 47% who have no opinion.

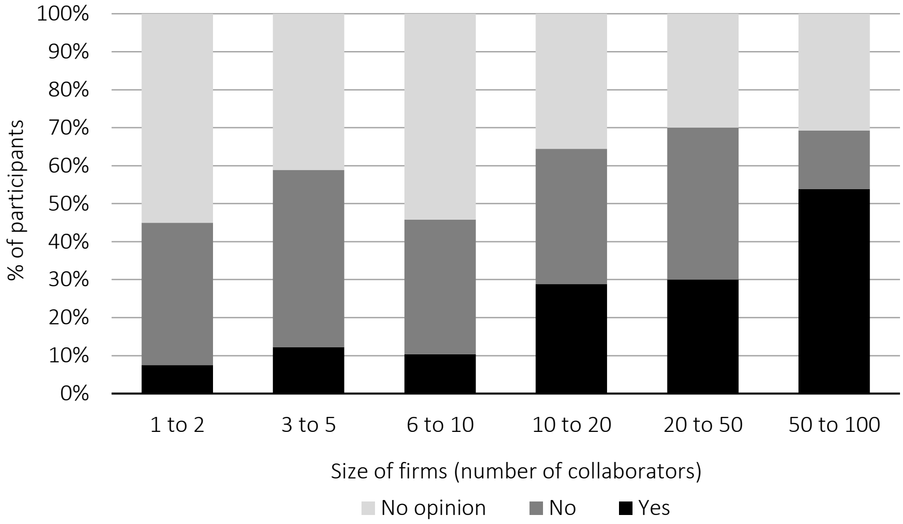


Figure 6. Interest rate for parametric tools depending on the size of the offices (Source: Author, 2018).

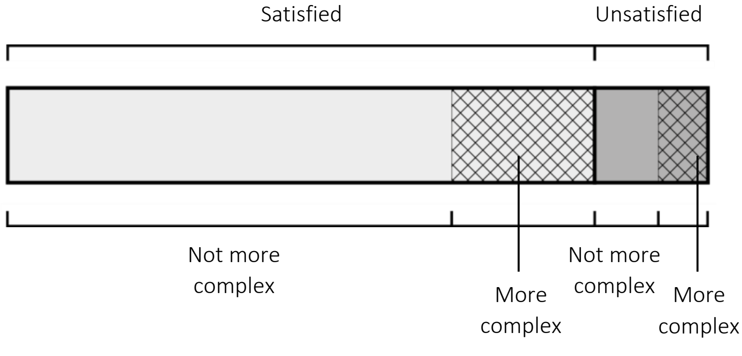
When it comes to the perception of the term "parametric tool" (understood here as software with a visual programming interface), among the 87.5% of the respondents declaring not using parametric tools (in regard to the question : "Do you use parametric tools?"), 57.5% of them refrain from suggesting a definition of parametric modeling (according to their point of view) while 2.1% designers prefer to skip the question. 40.1% of these "non-users", on the other hand, try and give a definition. Out of this group, 18.8% associate it with BIM process in regard of the definitions they provide, for instance *"drawing software such as BIM", "BIM or the ability to extract data from the project model".* Another 53.6% provide an incorrect definition. Answers such as *"ability to output 3D, 2D and cuts generated by the model", "complexity of shapes", "whim of the 2000s" are indeed considered as poorly representative of what parametric modeling really is. As for the remaining 27.6%, the provided definitions are more adequate although not complete, e.g.: "encoding of rules that will result in one or more forms, changes of parameters to change the shape", "a huge power of shape parametrization".*

Globally speaking, one can observe that some designers are able to explain the methodology but do not grasp the added-value parametric tools might have for their own practice. Others associate some strong mathematical notions to the term, generating a perception of complexity (one of the respondent for instance quotes: "*A modeling of complex shapes using mathematical formulas*."). Moreover, the parametric modeling is obviously associated by some of the non-users to larger architectural projects: *"an advantage for large projects", "bad, ugly and uninteresting architecture like NOX and Zaha Hadid or very generic architecture", "something that has nothing to do with the job I do today ... Like any technology, its value depends on how it is used".* The Belgian architects surveyed indeed generally associate the term "parametric" to three well-known architects and their offices: Zaha Hadid, Frank Gehry and Foster & Partners. This misunderstanding of the term is also observed when looking at numbers: 82% of ArchiCAD© users indeed think it does not rank among the parametric software; yet this software can be considered as belonging to the BIM category given its library of parametric objects.

Conversely, 83% of those who have taken the plunge of parametric software (as we understand it), and who do use a plug-in such as Grasshopper© are aware of doing parametric design. In that regard, 95.7% of the architects actively using parametric tools have given an explanation of what this term means to them. 3.3% of them provide what can be considered as a wrong answer with no regard to the real added value, e.g. "*image created on basis of points defined on the X and Y axis*". Another 2.8% associate the parametric term only to the BIM process and 93.9% of those who use parametric tools give a complete definition, such as: *"Design by using certain parameters (see i.e. Grasshopper). The term is mostly associated with the flamboyant forms of architects like Zaha Hadid or Frank Gehry but the technique could also be used for less extravagant designs, i.e. to design a façade system, vegetation scheme in a landscape plan...".* It therefore seems that the more parametric tools one uses, the more coherent the definition of the term is.

Impact of digital and parametric tools on architectural practice

Looking at how digital tools have impacted the architectural practice (specifically in regard of the satisfaction of use and the complexity generated), our results show that 83.5% of the respondents are satisfied with the digital tools they use, leaving 16.5% of surveyed designers unsatisfied. While 58 people (13.5%) did not answer, 27.4% find that digital tools have made their work more complex in general. Among the satisfied designers, 75.9% of designers are not only satisfied but consider that the digital tools do not make their work more complex (Fig. 7). Listing the top factors complicating architectural practice nowadays (in response to the question "*List 5 factors that complicate your architectural practice nowadays? (Rank them in order of complexity))"*, digital tools are among the top six factors, side by side with administrative formalities (stated 285 times); regulations (and more specifically planning regulations - 230 occurrences), "PEB" certification (Belgian building energy efficiency certification – 134 occurrences), evolving building techniques (111 occurrences) and customer requests (107 occurrences).



The question "*Are you satisfied with the digital tools you use in architectural design? Yes/No*" is crossed with "*Do you consider that the arrival of digital tools has complexified your work in general? Yes/No/no opinion"*

Figure 7. Designers and their digital tools: perception of satisfaction and complexity (Source: Author, 2018).

If we go deeper into the analysis of complexity in the design process, Figure 8 shows that the perception of complexity in architecture in regard of digital tools globally increases with age. A generation effect is nevertheless observed for the age group 41-45. 67.1% of that age group indeed find that digital tools do not make their work more complex: the main reason being that digital tools have allowed them to save time in particular thanks to 3D visualizations and easier collaboration with stakeholders. We can expose some representative quotes such as: *"No more India ink, razor blades and layers ...", "speed of design, assisted design, fast changes, data exchange", "It's a huge step forward in the visual presentation of*

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the files. The client immerses himself directly in the project and understands it directly. 3D can also improve your creations.", "improved coordination across disciplines". We also have to notice that architects between 41-45 are less prone to find that digital tools have complicated their work, the proportion being close to the corresponding one in the "under 30 years" category. This may partially mitigate the observed global generation effect.

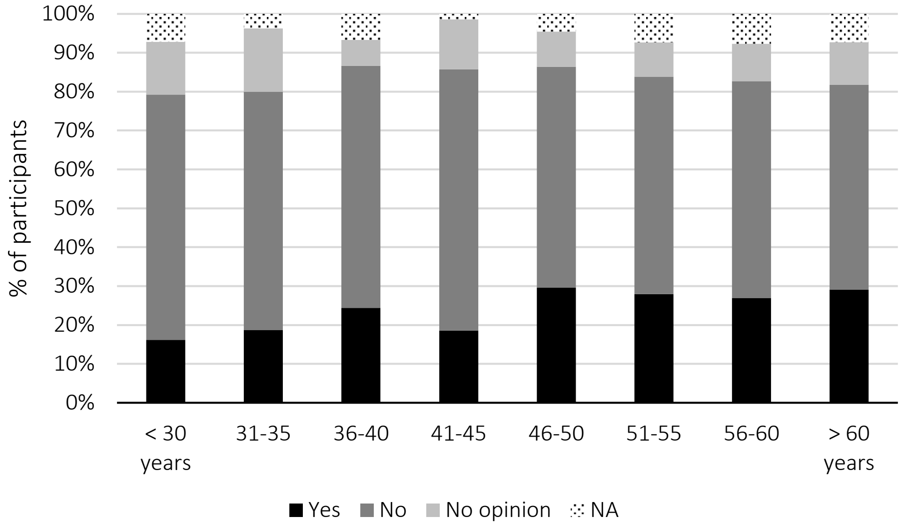

Figure 8. Growing complexity of architect's work with the advent of digital tools, in regard with age (Source: Author, 2018).

The survey moreover asks the participants to evaluate how design tools impact several factors of their architectural practice (Fig. 9). Most of them agree that digital tools have strongly increased the execution speed of projects, strongly facilitated exchanges with stakeholders and the implementation of projects, but they state digital tools have not at all promoted diversity of the shapes produced. Excerpts of free-field answers such as *"complex shapes are difficult to represent"* (e.g., curves) and "*non-standard element is complex"*, generating *"less creativity"* bring qualitative support to this result.

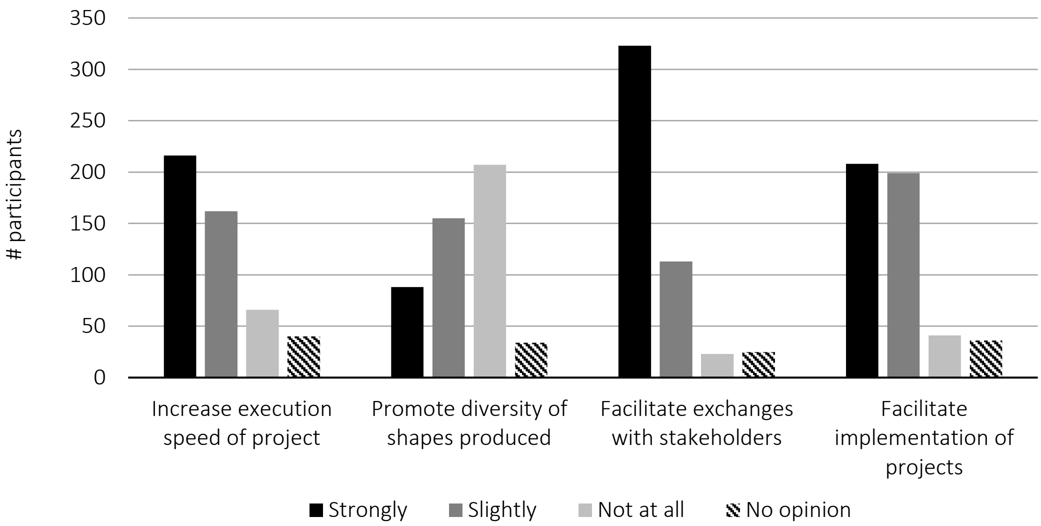

Figure 9. Influence of digital tools on several factors of the architectural design practice according to Belgian designers in response to the question: "The digital tools you use in architectural design as part of your projects...." (Source: Author, 2018).

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To fully understand the influence of the digital factor, we add here some results looking at how digital tools modify the architects' roles, from their point of view. Designers seem first divided when it comes to the designer's intent, and how it might have been impacted by the digital era (38.3% totally agree – 25.0% slightly agree – 27.6% not at all agree – 9.0% no opinion). They rather agree (52.8% agree - 23.5% slightly agree) that digital tools have modified their control over the implementation of the project (15.6% not at all agree, 8.0% no opinion), and at the same time are not sure about the impact on control of building costs (30.9% for improvement – 22.4% slightly agree – 35.2% not at all agree – 11.5% no opinion).

Considering the perceived effects of digital tools, we then question more specifically the impact of parametric tools on the design process under the question: "*According to you, parametric tools…*". Figure 10 lists several potential impacts parametric tools might have on the design process (as documented by Oxman & Gu, 2015), and presents how our survey's participants evaluate these impacts (from "it facilitates" to "it complexifies" through "I do not know"). The proportion of "I do not know" answers reflects the lack of information about the role of parametric tools described in the previous section. Indeed, between 54.1 and 71.4% of participating designers do not know the value of parametric tools, confirming the analysis that 51.5% of participants have even never heard of "parametric modeling". However, when giving their opinion, architects appreciate the interest of using parametric tools. We refer to remarks like the following one: *"The use of a set of parameters and various functions defining one or more geometries and one or more interactions between them, in order to create a final "shape" that is evolutionary, variable, and easily adaptable according to the variation of the basic parameters, unlike a direct sketchup model, which is more laborious to modify later, and not "implementable".*

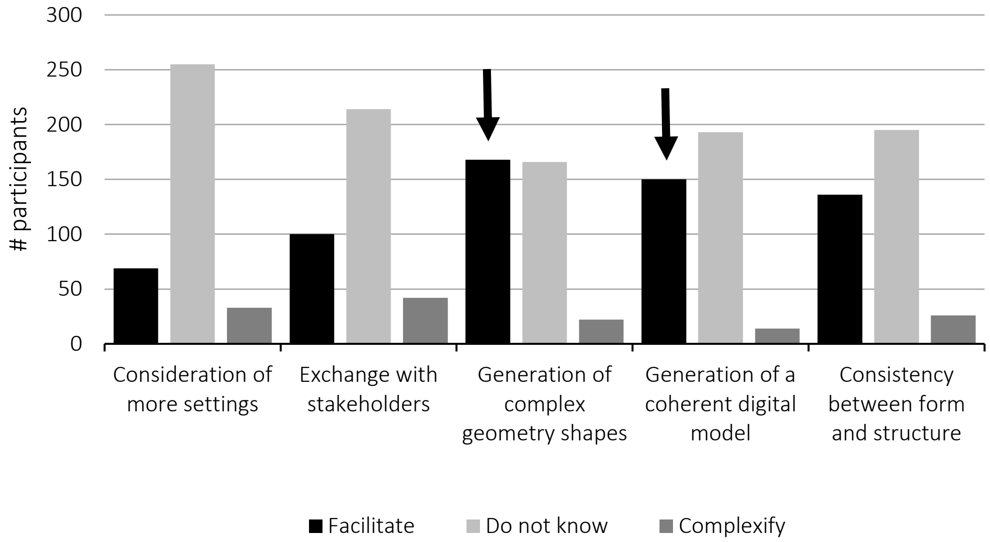

Figure 10. Influence of parametric tools on several factors of the architectural design practice according to Belgian designers (Source: Author, 2018).

The comparison of the impacts of digital tools on Figure 9 and the effects of parametric software on Figure 10 brings out another comment about promoting the diversity and complexity of shapes. Even though Figure 9 shows that a large part of the interviewed designers agree that digital tools have not at all promoted the diversity of shapes produced, Figure 10 indeed shows that parametric tools, on the other hand, do facilitate the generation of complex geometry shapes. Black sticks on Figure 10 indicate when participants believe parametric tools make much easier the generation of shapes with complex geometry, while generating a coherent numerical model that keeps and coordinates changes all along the process. Generally speaking, participants moreover recognize that parametric tools facilitate different aspects of the design process (taking into account more parameters, exchanges between stakeholders, consistency of form and structure). To go deeper into the understanding of parametric tools' impact on complex geometry, the following chart (Figure 11) details this trend by partitioning participants that do use vs. that do not use parametric tools. To ensure that these data could be compared, we used the Mann-Withney statistical test. The hypothesis that the use has no effect on the perception of the use of parametric tools can be rejected in a highly significant way (p-value < 0.01). Looking at data this way, it seems that designers using parametric tools do much more agree (proportionally speaking) with the fact that parametric tools facilitate the generation of complex geometry, while non-users more largely think tools make this generation more complex (or either say they do not know).

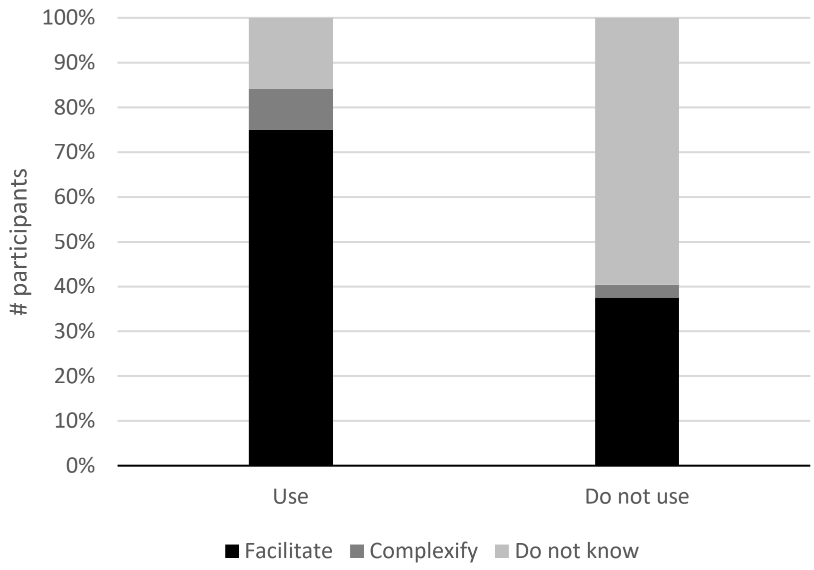

Figure 11. Effect of parametric tools on the generation of complex geometry shapes depending on the use of parametric tools (Source: Author, 2018).

This last graph shows that parametric tools can somehow bridge the gap generated by the adoption of traditional digital tools in regard of the diversity of shapes, by providing a way for willing architects to (at least) facilitate the generation of more complex shapes.

DISCUSSION

Our study focuses on the role and impact digital tools, and parametric ones in particular, have on the architectural practice taking place in the large proportion of Belgian small and medium architectural firms. The Belgian case, with its representative firms' size distribution (table 2), indeed confirms the need to devote a larger part of research to small offices' day-to-day work. Our research therefore closes the gap between studies about parametric practice conducted in large offices, and general studies about digital practice conducted in smaller structures.

In small offices, the first difficulty lies in the understanding of the term "parametric" itself, and in the understanding of which software are considered as such. The term "parametric tool" oversees two subclasses which definitions depend on how the software manage iterations. Associative modeling tools (supporting BIM processes), on the one hand, are more and more popular and even used in the workplace while dataflow and procedural modeling (referring to visual programming), on the other hand, still remain underdeveloped. Thanks to the data collected through our online survey, we can observe that the misunderstanding of the parametric concept itself may in part explain the tools' limited use, at least inside the Belgian landscape of small and medium architectural firms.

Globally speaking, one can observe that designers are generally able to explain the methodology specific to parametric tools but do not grasp the added-value parametric tools could have for their own practice. Moreover, they associate to the term some strong mathematical notions that might generate an impression of complexity and fear of use.

Considering the use of digital tools nowadays, we see that more than 75% of designers use digital tools, but only 12.5% use parametric tools according to their purpose. Only 14.4% of the participants state “being concerned” about the arrival of the parametric tools, and 51.5% have ever heard of the term itself. There is thus a real lack of interest for parametric tools compared to other types of more traditional software such as the ones supporting BIM processes. This difference is notably due to the fact that designers associate this practice to *“larger and more complex projects”* as well as larger offices. Indeed, we observe that the evocation of the term “parametric modeling”, the understanding of it, as well as the fact of feeling concerned about it, are following a slight growing tendency with the office increasing in size. In practice, parametric tools are also more used for engineering calculation, leaving aside their potential for the Belgian architects main mission (in regard of typologies of projects undertaken), that is the design of residential projects.

Concerning the perceived complexity hidden in their day-to-day work, and although our results show that 83.8% of the respondents claim being satisfied with the software they use, digital tools remain among the top six factors considered as source of complexity in the architectural practice nowadays. The architects also seem to be more impacted by the use of digital tools as their age increases. Beyond this aspect, architects state that digital tools have promoted some aspects of their design processes such as the speed of execution of projects or the exchanges between stakeholders. The diversity of shapes produced is however differently perceived, as 42.7% of the designers consider that digital tools have not at all promoted such diversity. Comments such as the following one underlines this paradox: “*not managing a 3D program perfectly can limit the design process for fear of not being able to model something”.*

When looking at how parametric tools in particular have impacted the daily architectural practice, our first observation is that there is an obvious lack of knowledge about the potential effects of parametric tools. As illustrated on Figure 10, between 54.1 and 71.4% of participating designers do not know the value parametric tools might have for the design process. Yet, we also notice that architects more regularly using parametric tools particularly appreciate the support in terms of generation of complex geometric shapes and the flexibility to manage those shapes: *“innovative approach that allows to generate shapes with complex geometry from the exploitation of a large amount of data”*.

It seems that the positive influences of parametric tools, as perceived and experienced by architects, may partly overcome the complexities listed over time. Formerly, as discussed in the *Morphogenesis through experimentation* section, the experimental processes generated complexity in terms of mathematical description of the shape, at that time not yet mastered. This complexity is nowadays overcome thanks to the parametric modeling process allowing both modeling control and flexibility. Digital tools in general provide a wider number of shape possibilities, although at first creating tensions between ideas and technical feasibility. With time, practice and expertise, it seems that parametric tools help taking into account from the start several parameters (Fig. 10), such as materiality and structure, this way bridging the gap towards an historic complexity generated by the integration in architecture of the first digital design tools, as developed in the section *First step into the digital era*.

CONCLUSION

The goal of this paper is to shed light on the influence parametric tools have on the day-to-day practice of small and medium architectural firms, as well as on the complexity of architectural design as perceived by these SME’s. To this goal, we sent a survey to 13.000 Belgian architects and architectural engineers. We collected 700 answers, out of which 572 have been considered valid and treated. The online survey is built in three main sections gathering firstly some demographic data about the participants, secondly data about digital practice and culture and thirdly data about parametric practice and knowledge.

In order to reveal which tools create the complexity of the daily work, we have analyzed the data from different angles. First, we can state that the very limited use, lack of interest and general misunderstanding observed when referring to parametric tools is understandable (given its relatively recent introduction into practice), but still necessary to overcome in architectural SME's. Statistically significant results support the observation that the size of the office stands by far as the main factor influencing the level of understanding and of interest when it comes to parametric tools. A sharp increase in knowledge of these tools is indeed observed as offices grow in size. From our point of view, the global misunderstanding occurring in smaller structures might partly explain why they generally delay, or even reject, their possible use. Another factor influencing the use of parametric tools is mostly related to the nature of the task to achieve: engineering calculations, compared to design of residential projects, more easily engage designers in using parametric tools, although residential projects constitutes the larger part of architectural SME's day-to-day missions.

Second, our results show how designers, globally speaking, state feeling limited in achieving the design of a diversity of shapes with traditional digital tools. In regard of the research conducted by Chase and Murty (2000), it seems that two types of complexity might explain this sense of limitation: the design complexity and the CAD complexity. The first one relates to the appearance of the designed object whereas the second one is about the CAD functions used to make a model. Our results address both these levels of complexity and show that SME's are currently still facing the second complexity while big offices seem to be progressively dealing with the first one.

Considering these observations, we investigate parametric tools as a potential solution to this lack of current digital support when it comes to morphological audacity. Looking especially at the diversity and complexity of forms, we argue that parametric tools, once they will have penetrated SME's architectural habitus, will carry the necessary potential to free SME's creativity.

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