Integration of Parametric Modeling Tools in Small Architectural Offices – Between Constraints and Organizational Strategies

Adeline Stals[a], Catherine Elsen[b] and Sylvie Jancart[a]*

[a]*Faculty of Architecture, University of Liège, Liège, Belgium ;* [b]*Faculty of Applied Sciences, University of Liège, Liège, Belgium*

sylvie.jancart@uliege.be*

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In order to succeed in today's disruptive world, architects have to constantly reevaluate their strategies and innovate. Consequently, some architectural offices have started to implement parametric modeling tools to support their ideation work. Architectural studies consider how such technologies impact the design process, cognitive processes or generation of representations. This paper looks at the impact of this approach from another angle, which relates to the organization; it focuses on parametric modeling adoption, and on how parametric modeling tools and organizational aspects of small offices impact each other. While parametric modeling is announced to be widely adapted, we give an overview of parametric practices in small and medium Belgian architectural offices, which represent the largest part of the market but are generally left aside in studies. This paper divides into four categories the main barriers and enablers architectural SME's are confronted with, when adopting parametric modeling. These lead to a system of constraints in which the architectural practice evolves. The research observes the management of parametric workflows in SME's and situates the parametric modeling tool within the theoretical framework of organizations. This study will help understand some of the factors limiting the adoption of those tools in SME's and will help architects when developing their strategy of adoption.

Keywords: Parametric modeling; design process; SME; emerging practice; organization; adoption

1. Introduction

Companies are challenged by the rapid evolution of technology. Consequences of these changes are different considering the field, size, history or habits of each organization (Pichault, 2013). The AEC sector, like most sectors, undergoes a digital transformation, where digital innovations deeply affect organizations (Azzouz & Papadonikolaki, 2020).

The practice of architecture is undergoing unprecedented change, partly due to the rapid evolution of digital technologies (Haidar et al., 2019; Kocaturk, 2019) in terms of collaboration (Fok & Picon, 2016), interdisciplinarity (Bhooshan, 2017; Lars & Benachir, 2011; Sprecher & Ahrens, 2016), or representation (Harding & Shepherd, 2017; Jabi et al., 2017) and affecting firms and projects (Azzouz & Papadonikolaki, 2020). Tools are becoming more adaptable (Burry, 2013), processes more flexible (Imbert et al., 2012; Tamke & Thomsen, 2018), and parametric modeling tools are playing a role in this evolution (Authors, 2021).

Witnessing this emergence, researchers have started investigating the impact of parametric modeling tools on architectural design processes. They report that architects demonstrate a growing interest for these tools, considering the new perspectives they open up in terms of workflow (Harding et al., 2012; Yu, Ostwald, et al., 2015), morphological diversity (Wortmann & Tuncer, 2017) or in mastering the constructability (Shelden, 2002) for instance.

However, it appears that architectural studies focusing on new tools development generally leave aside smaller-size offices, and the influence of their organization on the practical implementation of those tools. Furthermore, they do not question the challenges the organizations have to overcome in order to implement these tools.

On one hand, some studies have indeed focused on stabilized practices established for several years in large international architectural offices. Others, on the other hand, have been conducted in experimental settings including controlled design conditions, appearing sometimes remote from actual architectural practices (Authors, 2018). That does not benefit the vast majority of architects from small and medium-sized enterprises (SME's), who are still struggling to cope with the fast digital transformation (Carpo, 2017); an adequate analysis requires small *and* large scale companies, and an empirical *and* an experimental approach. This coexistence is essential to avoid the development of technologies that are too far removed from the needs of the sector and therefore not sustainable.

Unlike research on well-known architects, this paper focuses on main stream architects. Slowly but steadily, these architects become ready to explore how parametric modeling tools could contribute to the development of projects better adapted to their expectations and creativity (Riccobono & Pellitteri, 2014; Authors, 2021; Terzidis, 2004). However, the use of such tools in such specific, small-scale contexts requires the development of customized strategies that are not yet understood nor mastered by scientists and practitioners. This paper focuses on the case of architectural agencies challenged by parametric modeling tools used during the initial design phases. How do architects working in SME's react to the digital transformation called for by parametric modeling? What are the barriers and enablers for adopting parametric modeling? How might the parametric modeling workflow and the office organization impact each other?

The questions raised are not isolated issues; they are part of and contribute to a larger research project that identifies the cognitive and organizational strategies and adaptations deployed for the implementation of parametric tools into the architectural design processes of SME's. The study of such SMEs' strategies from the perspective of the theory of organizations thus constitutes an original angle, prone to complement the point of view of other studies conducted in the field of parametric modeling.

First, this paper explains the theory of organization. Second, it addresses specific cases of architectural SME's in the middle of their digital transformation, when implementing parametric modeling tools. After that, the results are presented as follows: an overview of parametric practices in Belgian SME's; a system of constraints beyond the observed postures to implement parametric modeling; two main user profiles of parametric modeling. In conclusion, this paper gives an overview of parametric practices in small offices and discusses the consideration of parametric modeling tools through the theory of organization.

2. Organizational approach

Changes always have a certain impact on the company's organization (Nizet & Pichault, 1995; Pichault, 2013); the context in which a technology is integrated is of fundamental importance. The theory of organizations is a helpful tool for this research to analyze the impact certain changes have on the organization of a firm, considering its history, established experience and operating methods.

Although the organizational approach is rarely considered in architectural studies, it makes it possible to understand technologies in a relevant and more global way (Scheffers et al., 2017). This approach puts into perspective the changes in action that may result from these technologies. Over the course of history, the link between technology and organization has been studied according to the evolution of technology itself, and its place in the organization

under study (Boyd & Holton, 2017; Nizet & Pichault, 1995; Orlikowski, 2000). In that regard, two antagonistic approaches dominate.

The first approach is the theory of technological determinism (Marshall & Burnett, 2003). This radical approach considers technology as the determinant of its uses; in this case, users adapt to the tool that sets the framework. In the architectural field, Sennett (2010) is among those who believe in technological determinism when it comes to technology impact on the design process and the final shape. From this point of view, Computer Aided Design (CAD) software can be seen as participating in a form of "rationalization of thought and hypertechnicization of the design process" (Amphoux, 2002). Used upstream of the project, these tools would constrain designers to comply with the possibilities offered by the software (Léglise, 2016). Technological determinism remains a dominant theory (De la Cruz Paragas & Lin, 2016)), especially when studying the impact a recent technology might have on design practices. However, this position has been severely criticized by researchers who address the fact that it does not sufficiently cover the diversity of possible interactions between man and technology (Chandler, 2002).

The second approach, the theory of socio-materiality, puts technological determinism into perspective. In contrast to the latter, socio-materiality considers that presuppositions are embedded in technology but that social context has a fundamental role and must be taken into account (Orlikowski, 1992, 2000, 2007; Holz, 2021). That way, a new technology might lead to different organizational choices depending on the context in which it is embedded. In other words, the use of the technology would not be totally determined but would vary according to the context; the tool can therefore be implemented in a large office as well as in a small one, and still show different uses and outcomes (Bruni et al., 2021).

The theory of socio-materiality offers to rethink the use of new technologies, since they are not considered as mere instruments used by people (here architects) to achieve their goals, nor as a determinant of human action. This approach views technology as a non-human actor which actively shapes cognition, skills acquisition or decision-making. By allowing actions that are not initially anticipated, or by revealing interpretations that humans do not initially possess, technologies can play an important role in the directions taken by action. In that sense, technology, and software in particular, can generate the development of new skills among users (Tribout & Margier, 2018) and open new paths of exploration for a project.

This research focuses on changes occurring in the architectural practices of small offices implementing new digital tools, in particular parametric modeling tools. By doing so, it will position the introduction of those tools in regard of the two previous theoretical positions. To understand the global context, the next section briefly comes back to the digital transformation occurring in architecture.

3. Digital transformation in architecture

Many disciplines have been immersed in the digital age for several decades. The architectural world is also facing this challenge, commonly referred to as *digital transformation*. For more than forty years, the transformation of the architectural practice has been speeding up due to the development and democratization of digital technologies and their integration into professional and private spheres. Architects have faced major digital developments, ranging from 2D-CAD to parametric modeling, BIM practices, digital fabrication, data science for ideation or immersive technologies.

Aish and Bredella (2017) discuss the generally low rate of digital maturity observed in architecture, since architects generally resist switching from one technology to another, each technology necessitating too much adaptation in terms of process and organization. Additionally, any late implementation of a technology means that users cannot fully benefit from the change, as the technology in question is already being overtaken by another one. The adoption of new technologies thus remains a challenge due to the changes they bring about in architectural practice, given the relationship architects hope to maintain with the context, the project's stakeholders and their roles and missions as "masters" of the project notably (Deutsch, 2019).

In Europe, and more precisely in Belgium, the amplitude of this challenge is such that architects often feel poorly informed or disoriented (Authors, 2018). Among other digital tools, parametric modeling tools are suffering from hesitant to low adoption in the architectural practice. The next section resumes the specificities of those tools.

4. Parametric modeling tools in architecture

Due to the variable nature of architectural design (Bukhari, 2011) and the unique character of each architectural artefact, architects expect a design process that supports and promotes changes. Some designers have therefore started to use parametric modeling tools, to support their early-phases thinking process. Originally developed for design within aerospace and automotive industries (Foster & Partners, 2006; Salim & Burry, 2010), such tools have been progressively "hacked" and adapted by large architecture companies (taking advantage of their "in house" teams of software developers), and from there on have been slowly diffused to smaller-scale structures.

From a semantic point of view, the distinction between the different types of parametric software and underlying parametric logic remains largely unclear, these ambiguities being discussed in a previously published paper (Authors, 2018). Some authors essentially compare parametric software to the ones supporting BIM processes, that are considered out of the scope of this study. In any BIM process, data integration corresponds to adding an additional layer of information to some geometrical model, while in parametric modeling, the data is dynamically integrated in a process of morphogenesis (Authors, 2018). The focus here is thus rather on algorithmic modeling software, specifically those with a visual programming interface (such as Grasshopper©), observed as the most widely used parametric software (Cichocka et al., 2017), and in the Belgian architectural field in particular (Authors, 2017). Those tools make scripts more accessible to the user, especially with little or no programming skills (Tedeschi & Andreani, 2014), through an interface where the designer manipulates graphical elements while generating their algorithmic chain at the same time.

The user thus constructs a directed acyclic parametric graph, composed of parameters and components to generate geometries (Aish & Woodbury, 2005). This approach requires the designer to develop an intermediate thinking step between the idea and the design (Authors, 2021). The designer produces an algorithmic description of the envisioned design (Leitão, 2013) including the logic and dependencies between input parameters and dependent geometric operations. At the end of the process, there is both a definition (the chain) and a specific instance (see Figure 1).

The development of such a graph is considered a new skill for designers (Oxman, 2017) and becomes part of the design process (Harding et al., 2012). This indicates a fundamental

shift from modeling an "object" to modeling the "logic" of its design (Anton & Tanase, 2016; Leach, 2009; Authors, 2021). If the algorithmic definition produced equals the process, then the architect no longer only designs a building, but also the process. This allows the architect to explore design hypotheses at any stage of the process in a way that was not possible with traditional design and modeling approaches (Aish & Bredella, 2017).

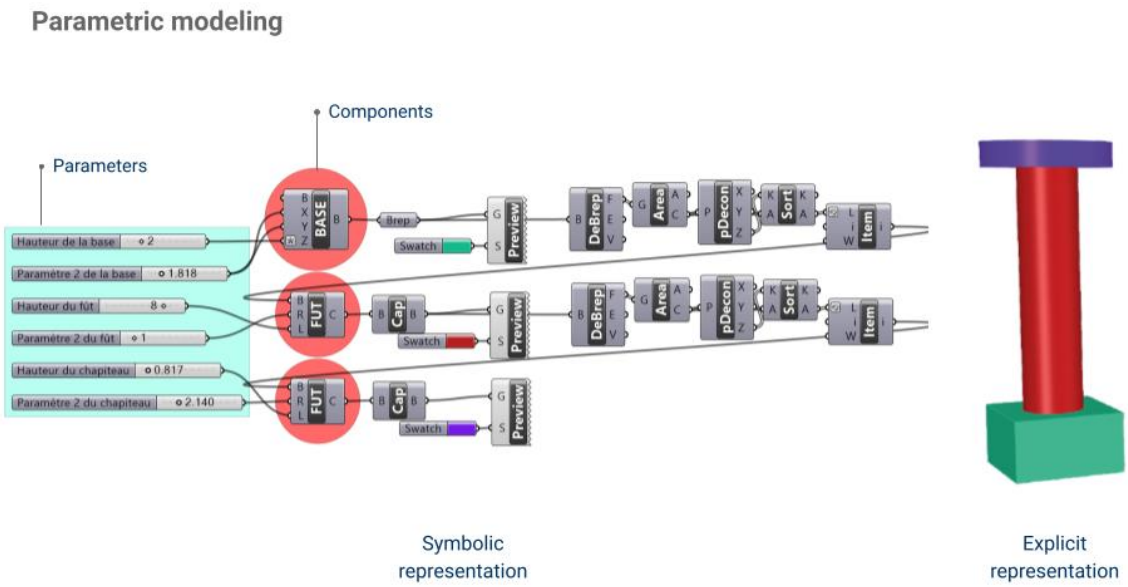

Figure 1. An algorithmic chain and its geometric representation.

Previous research tends to announce that parametric practice is now established in architectural offices (Harding et al., 2012; Yu, Gero, et al., 2015). These studies rarely put forwards quantifying and describing the state of actual practices (their maturity, the adoption processes) in architectural offices. A previous paper shows that the majority of those studies are conducted in experimental academic or in large architectural offices, which do not reflect the practice of the majority of architects (Authors, 2021). On the contrary, few researchers question the practices of small offices and their adaptations considering specific needs and means. Yet, a European survey studying the architectural profession in Europe in 2018 (Architects' Council of Europe, 2019) reveals that 99% of architectural offices are composed of less than ten people, and even 71% are composed of only one person. This survey shows that the number of medium-sized offices is decreasing in favor of even smaller structures. Therefore, this research project concentrates on the challenges those small-size organizations face when they implement parametric modeling tools. A large-scale online survey was carried out; in addition, the authors of this paper conducted in-depth, semi-directive interviews with respondents.

5. Methodology

This paper adopts constructivism as an appropriate theoretical basis, relying on the on-field collection of quantitative and qualitative data. These data, collected through mixed methods, are relevant and complementary to the research subject. Such a combination of methods allows for balanced and nuanced results (Johnson et al., 2007).

With the support of an existing theoretical framework to which data collection can be confronted, an exploratory sequential design was preferred to structure the research phases (Creswell & Clark, 2017). The quantitative approach is used first, in order to conduct an exploratory phase. A large-scale survey makes it possible to problematize and empirically initiate the understanding of digital practices, while providing an overview of the community and its general knowledge with regard to parametric modeling. In addition to this approach, in-depth interviews are conducted to refine the mapping of the challenges associated with the implementation of parametric modeling tools and to identify associated organizational dynamics (Recker, 2012). The methodology is based on a bottom-up approach that allows for specific strategies implemented by architectural SME's, without developing any preconceived hypotheses; the theory of organizations is retained as a meta-theoretical framework, which is helpful to structure the argumentation.

5.1. Large-scale online survey

To investigate the digital practice and the parametric knowledge held by architects, the survey questioned the Belgian community and its large proportion of small and medium architectural offices, about 13.000 architects or architectural engineers registered in the different regional Architects Associations, out of the 14.482 members registered in 2016 (OdA, 2016). The choice fell on an online-based survey to reach the largest possible community and be as representative as possible.

The questionnaire was built around three 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, 7 semi-open and 2 closed-ended questions) mainly relating to the participants' gender, age, background, expertise, main day-to-day tasks and size of the firm. The second section questioned the designers' digital culture, the digital tools they used on a daily basis, their feelings about those tools and their impact on the architectural design process. It contained 26 questions (6 open-ended, 10 semi-open and 10 closed-ended questions). This paper presents the data of this second section that informs the organizational aspects of parametric modeling implementation; other results, focusing on the role of digital tools in multidisciplinary work for instance, have been published elsewhere (Authors, 2016). The concluding section of the survey, investigating parametric design and tools, was structured around 9 questions (1 open-ended, 1 semi-open and 7 closed-ended questions). It discussed the understanding of the concept and the impact in practice. The complete survey is available on request to the authors.

In order to clarify the meaning of some statements and to define the exclusion criteria, the questionnaire was first tested with three architects. Eventually, 572 out of over 700 responses collected were selected for analysis (reasons for rejection including: completion time under 15 minutes; only first section completed). This amount represents 4.1% of the architects registered in the different regional Architects Associations, which can be considered a low answer rate. Descriptive statistics of the sample however demonstrate a global alignment of the respondents' profiles, in comparison with other larger survey campaigns (for details, see Authors, 2018).

5.2. In-depth interviews

Qualitative in-depth interviews were conducted in order to investigate the third part of the survey more profoundly. Participants of the survey were able to indicate their willingness to further discuss the research topic, be they users of parametric modeling in their day-to-day architectural practice or not. Thirteen people chose to participate; eleven interviews were conducted by phone and two interviews were face-to-face. This seemed to be appropriate for the interviewees and did not call into question the methodological process in place.

The semi-structured interview method was used to interview participants. In order to develop the interview grids, the architects' profiles were classified according to the accuracy of their response to the online survey question: “What does the term ‘parametric modeling’ in architecture mean to you?”. Three categories of response were used: correct, incomplete or wrong definition. Participants also stated if they used parametric modeling, considered using it in the near future or did not consider it at all. Considering the possible profiles, six interview grids were developed (available on demand) to adapt the inquiry to each specific context and were built according to the same structure. The interview began by delineate the participant's knowledge about parametric modeling tools and the origin of this knowledge. The section contained between one and four open-ended questions depending on the questionnaire. The second and main section referred to the accuracy of the definition formulated about parametric and the use of parametric tools. A general section about the potential use of these tools in small architectural offices ended the interview.

The following sections present and discuss the results gathered after analyzing the data of both the large-scale survey and these interviews. All respondents’ comments have been translated by the authors for this paper.

6. Results

6.1 Overview of parametric practices in small Belgian offices

Table 1 validates the interest of refocusing research on smaller firms and the relevance of the Belgian case since, according to the survey, 42.7% of the Belgian respondents work in an office of one or two architects and nearly 80% of them work in a structure with fewer than 10 people. These trends confirm the importance of a thorough understanding of the day-to-day work of those offices.

Table 1. Size distribution of firms in Belgium, considering the survey sample (N= 572).

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%

Generally speaking, the results about digital practices in SME's highlight the skepticism of architects when it comes to the added value of digital technologies to the architectural design process; moreover, they demonstrate their skepticism and low-acceptance rate when it comes to parametric modeling tools specifically.

To the question "What does the concept "parametric modeling in architecture" evokes for you?", more than half of the respondents (51.5%, N=369) answered that they have never heard of it. The results show that the bigger the office, the more likely people are to know and understand parametric modeling. The same tendency is observed in Figure 2 concerning the interest rate for parametric tools: the X axis shows the increasing size of the firms, the Y axis represents the percentage of participants who have an interest, have no interest and have no opinion on this issue. To validate these trends, the authors have tested whether "yes" and "no" answers were equally distributed by size of offices. To do so, the Mann-Whitney U statistical test was used, 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). In conclusion, the smaller the offices, the less interest they have in modeling parametric tools. Additionally, the results underline that only 14.4% of the respondents state "being concerned" about the arrival of these parametric tools on the market; 38.6% of the participants show no concern and 47% have no opinion.

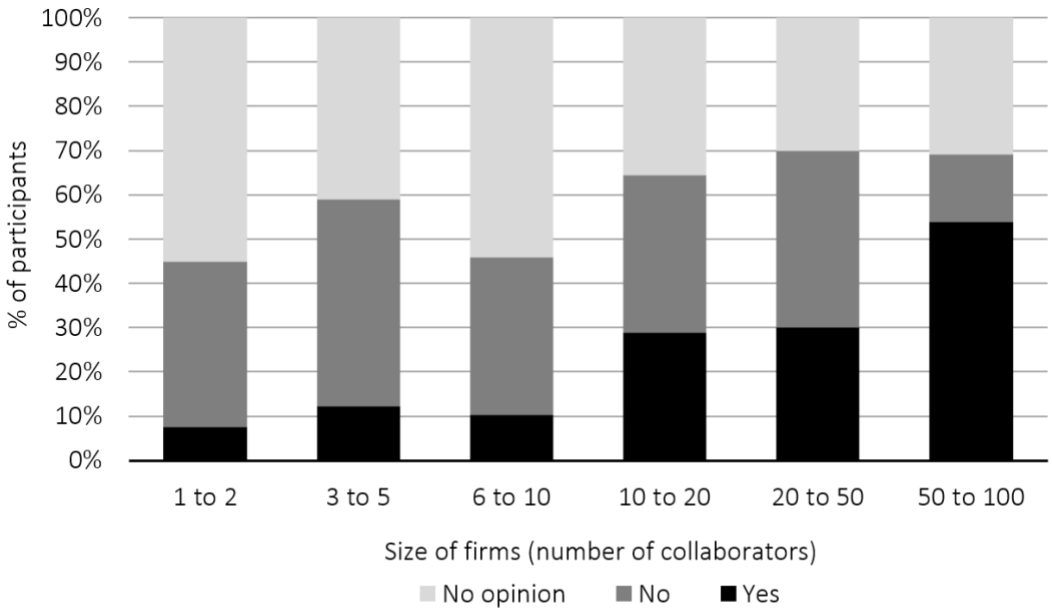

Figure 2. Interest rate for parametric tools depending on the size of the offices (N= 376).

Accordingly, 87.5% of the respondents say they do not use parametric tools because they consider them to be mainly designed - and better suited - for large offices working on large-scale projects. Interviews include comments such as "*So here, apart from projects, really big projects like Zaha Hadid [...] Or at least from what I know, it's not, it's not really adopted yet*". This lack of knowledge leads to an unwillingness to transfer such technology to their field of expertise, because architects don't necessarily perceive the potentiality of "*valorization of the tool*". Challenging these stereotypes seems to make one of the interviewees feel uncomfortable: "*perhaps the question is stupid in itself, is there a use, possible uses of this type of tool, an interest, in using tools like these, in the production of forms that are basically [...] perhaps*

more conventional". Parametric modeling tools are generally promoted by architects belonging to large architecture firms, or researchers who analyze these practices and present their experiences or their new flagship project. The interviewees working in small offices point out that these contexts reinforce their perception of inadequacy and irrelevance when it comes to integrating parametric modeling into their daily work.

In the next section, it becomes apparent that a whole system of situated constraints may partly explain architects' reluctance, or on the contrary curiosity, when it comes to parametric modeling.

6.2 A system of constraints beyond postures

While Bourbonnais (2014) divides the architectural community into two main groups (those who easily adopt technologies and the so-called "technophobes", who are reluctant to implement renewed modeling methods on a daily basis), this paper goes beyond this duality by identifying a system of constraints that shapes the architects' reality, and through which they attempt to develop their own practice (or justify their lack of commitment when it comes to acquiring new parametric skills). This system of constraints includes cognitive and temporal constraints; organizational constraints; contextual constraints; and so-called "exploratory" constraints. It partly explains the low adoption of parametric modeling tools. These constraints indeed challenge the architects' perception of a tool, and the capacity of this tool to support architectural design.

6.2.1 A cognitive and temporal constraint

The majority of the interviewees believes that it is necessary to have specific expertise and skills, which most of them do not have, in order to be able to use the tool and its interface in a relevant and effective way: "*Besides, since I didn't understand it well enough, I'd waste more time trying to use it*". It is time consuming to acquire these specific skills and to stay up to date with the upgrades, but lack of skills can lead to uncertainty and lack of control over the process.

Although some architects are open to learning how parametric modeling works, the difficult nature of the learning process clearly is a stumbling block rather than an incentive to develop one's skills. It even becomes a constraint that discourages some of the potential future users: "*It gives the impression that these tools are often created by computer scientists and therefore it is not the same logic*".

In addition, concerns have been raised about the time required to become familiar with such a tool and to define and implement the parameters, especially in a competitive fast-paced market environment. This imperative of efficiency and speed in the design work seems to predominate over the quality and potential offered by the software, perceived as "too innovative" and irrelevant.

6.2.2. An organizational constraint

The ubiquitous use of general CAD software cannot be called into question, as it is now one of the founding elements of effective collaborative systems established between stakeholders, notably when those stakeholders do not work physically together. It is therefore essential that any implementation of *new* technology does not destabilize the implementation

of *other* tools, nor the cooperation with the various actors in the process, from design to project construction. The majority of the respondents considers the acquisition of new software to be an inconvenience, as its integration implies disrupting habits and practices. Once the software is implemented, an organizational strategy must be defined based on the skills of each employee, to overcome the difficulty of working on a shared project using that tool. This strategy differs from one agency to another and can be defined rigorously or not, leaving room for employees to seize opportunities according to their technological affinities: "*at some point, we must find the time and develop skills to identify an opportunity for optimization, and to say to ourselves that we will generate a routine, develop it and pass it on [to the team]*".

Thus, the interviewees consider and assess the relevance of this typology of tools from the perspective of their work practices and routines, even though parametric modeling disturbs traditional design and collaboration methods. The role of the different expertise in the design process and eventually the modalities of collaboration between actors should be reconsidered in light of the new ways of working generated by parametric modeling. According to some interviewees, a new profile of expert should be considered in such a context. The parametric practice, in this case, could be fully outsourced to this other expert, who is generally detached from the design process: "*I just have to explain to them [agency partners] that what they put in the building permit is not possible [to model]*".

6.2.3. A contextual constraint

The contextual constraint is related to the context in which the actors operate: this seems to heavily impact the appropriation of such parametric tool. Faced with the diversity of skills one needs to adapt to the growing and perpetual demand for specificities (energy analysis, BIM modeling, ...), architects do not seem to have the necessary resources (in time, training, or economically speaking) and feel trapped in a rapidly evolving system. As a result, they only seem to consider change in a context of pressure. Architects seem to prioritize the integration of tools that either allow them to meet the evolving ambitions of clients or to outrun the competition, rather than considering tools that might enhance their processes. For now, many of the interviewees agree with this statement: *"because the customer is simply not asking for it"*.

Thus, the client's influence (his/her requests, the complexity of the project) or the requirements of the administrative services are generally identified as levers of change (First Author, 2019). These contexts seem to have a permanent influence on the choices and orientations in which designers engage.

6.2.4. An exploratory constraint

Some architects are skeptical, and tend to argue that the use of such software would impact the decision-making process all along the conceptual phase, and thus modify the nature of the latter (positively or negatively). The most skeptical architects are concerned that creativity might be lost because of the accuracy of the software, which repeats precisely the same result at the end of the same process. According to them, this type of software gives the illusion of a renewal of the aesthetical and formal research, but in the end actually reduces possibilities and alienates creativity.

For the less skeptical architects, the adoption of such software is not a risk but rather an opportunity to go beyond the possibilities offered by traditional ideation processes (be it mentally, on sketch or *via* CAD tools) and to support the research phase of the design process.

In this case, architects do not fear to have to comply with morphological constraints induced by the software. They rather see in the software the opportunity to promote self-critical evaluation towards possible morphologies: "*Objectivize the parameters and sometimes contradict yourself. We thought that, and by going through the filters of the software, it will show us that it was quite the opposite and that we should change our mind. But already very early in the project*". From their point of view, the parametric tool allows to explore other possibilities that they did not initially anticipate. However, architects feel torn between this time-consuming opportunity and the conditions of their practice.

The next two sections develop the point of view of two main profiles of architects working in SME's, as delineated through the research. These profiles echo various socio-assemblages of the previously listed constraints. The first group consists of the "skeptical architects", who lack interest and digital literacy and are not interested in parametric tools. The second group consists of the "novice architects", who are not really experts but interested in learning such tools, thus slowly mastering the underlying algorithmic logic.

6.3. Two main users' profiles in the context of parametric modeling

6.3.1. Skeptical architects, outside the scope of parametric use

Architects who have founded architectural offices of their own have already experienced several digital transformations, from the free-hand drawing to the very first steps of CAD. Although it is widely recognized that the tools have evolved for the better, allowing for easier edits and for straightforward interactions between stakeholders, these digital transformations have left some scars. Architects had to invest time and effort to adapt and develop an adequate system to meet each new tool's requirements. Some architects, who are settled in their habits, do not see, or do not want to see, the added value of new tools, representing yet another change.

Those skeptical architects are reluctant to use parametric modeling. Since they do not understand the principles underlying the operation of parametric software, "*because we [architects] are not computer engineers*", they fear that they will lose control over the shape definition and the design process as a whole. Research by Yu and his colleagues (2015) shows that, in the parametric process, designers still put a lot of effort into considering the context and program as in any "traditional" design processes, while algorithmic definitions are mainly used to support their intention to generate models. In that regard, one might argue that parametric modeling would not generate a loss of control but would *reinforce* control, in the shape of the precise and "augmented" management of the data feeding the generation of the form.

In conclusion, architects who put themselves outside the scope of parametric practice do not yet have (or want to have) the level of digital literacy to understand that parametric design tools can offer many new possibilities, given their accuracy and their use of algorithmic definitions.

6.3.2. Novice architects in parametric modeling

Unlike skeptical architects, the novice architects are definitely willing to learn parametric modeling; however, they face difficulties of their own. For novice architects, the main challenge to learn and use this software is the cognitive effort they have to put into it, which may cause inertia. Indeed, technical issues related to the interface or to the tool may divert their

attention from the exploration of the architectural problem/solution space. The users would be tempted to opt for procedures and operations that are within their control and take less time but may be less appropriate (Borillo & Goulette, 2002). The generation of ideas is impacted by the tool: the novice architects are easily diverted by the complexity of the technology, modeling not what they really want, but what is easiest to do and within their reach considering their skills (Robertson & Radcliffe, 2009). This attitude is reflected in the circumscribed thinking phenomenon.

In addition, novice architects emphasize the value of parametrics given the "surprise factor" of this technology. Chien & Yeh (2012) argue that these "unexpected results", induced by complex parameters, result mainly from a lack of understanding of computer programming, mathematics, in particular geometry, rather than from actual added value of parametric modeling tools. The observations here show that this phenomenon occurs more often among novices than among experts. While this can be attributed to the novices' inexperience, the unexpected discoveries that are sometimes generated by expert architects are nevertheless a real consequence of the added value of parametric modeling; namely, the interaction with the model and its potential to adjust parameters.

7. Discussion

7.1 A panorama of parametric practices in small offices

The results show how the expertise of architects in parametric modeling can be articulated within an SME. Figure 3 summarizes the different approaches observed in the SME's that do manage to implement parametric modeling. The terms defined should be considered in relation to an architect's expertise in parametric modeling, without questioning his/her *general* expertise.

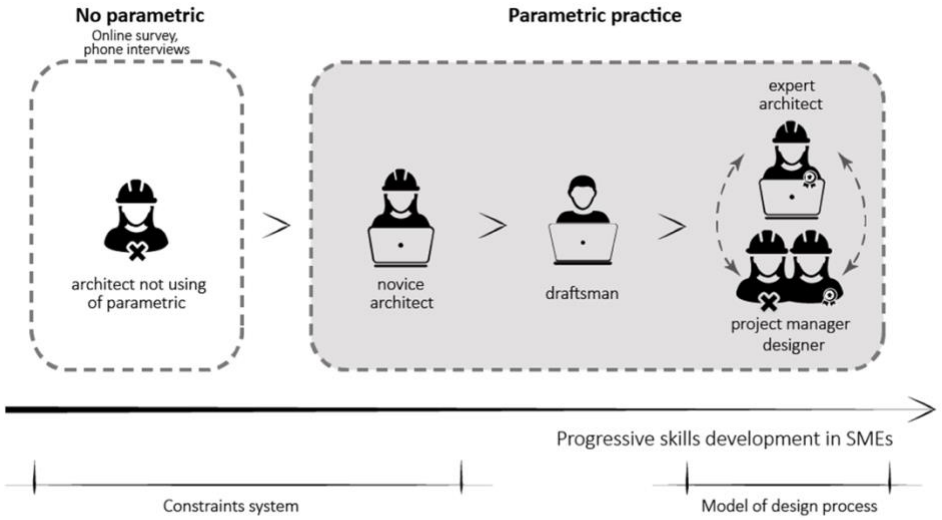

Figure 3. Approaches for the implementation of parametrics in SME's, with regard to the expertise profile.

On the far-left side, the figure includes architects with no parametric expertise who, as the results suggest, suffer from some form of inertia when it comes to their digital practices,

reinforced by skepticism as well as disillusionment with the benefits that parametric modeling bring to the design process.

On the right side, the figure illustrates parametric practices in regard to levels of expertise. First, there are architects who are novices in parametric modeling. The previously analyzed two levels of expertise ("skeptics" and "novices") support the specification of a system of constraints within which their practices are embedded. In the middle, the parametric practice of a draftsman who is detached from the design process itself is considered; he/she is the person to whom architects have outsourced the execution of parametric modeling, he/she generally lacks the fundamental skills that an architect develops and acquires through practice. Finally, on the far-right side, readers find the architect who is an expert in parametric modeling. His/her expertise redefines partnerships with colleagues, whether or not the latter know how to use parametric modeling; their expertise even has the potential to fundamentally change the organization's strategy.

These four profiles, linked to a level of expertise and attributed a specific role in the design process, demonstrate how architects might relate differently to parametric modeling, and how parametric modeling on the other hand might impact the ways of working inside a SME. The position of parametric modeling tools in light of the theory of organizations is discussed in the next section.

7.2 Architects' perceptions of parametric modeling tools studied through the theory of organizations

This paper approached the theory of organizations by considering two major theories: technological determinism and socio-materiality. These theories consider the place of technology in an organization in a divergent way, the first considering that technology determines the use; the second attributing to technology certain presuppositions while the social context plays a fundamental role to take into account. Considering these different approaches and the profiles sketched out, it can be said that skeptical architects tend to view parametric modeling through the lens of technological determinism, mainly because of the rather limited options those tools supposedly impose on its users.

Indeed, most of the skeptical architects argue that these tools would automatically inculcate the design with a particular architectural style. This, as the survey demonstrates, is the consequence of the digital culture which has an impact on the a priori that architects who do not use parametric modeling can forge for themselves. They unhesitatingly attribute parametric modeling to one particular architectural style, typical of large-scale projects designed by renowned firms which they consider irrelevant to their personal practices. In particular, they repeatedly list three architects (Zaha Hadid, Frank Gehry and Foster and Partners) to illustrate their vision of architecture developed with those tools. According to their vision, technology is the determining factor in terms of architecture, generated both formally and symbolically.

However, architects with some knowledge about parametric modeling have shown that the context and their expertise are of significant importance to the project; they can influence the non-systematic use of parametric potentialities. This approach is in line with the socio-materiality, which still does attribute certain presuppositions to technology, but also acknowledges that the context plays a fundamental role. This approach makes it possible to rethink the use of the technological tools; they are not considered to be mere instruments

mobilized by humans to achieve their goals, nor to be complete determinants of human action. Rather, they are intermediate objects, impacting the output while supporting the architects' ideation processes.

8. Conclusion

Previous studies on parametric modeling have demonstrated the potential of this typology of tools for architects. However, few studies address their adoption or give credit to the influence that the organization and its size might have on this adoption. That is why this paper aimed to give an overview of the state of knowledge and practices of parametric modeling in small Belgian offices, and to discuss how parametric modeling tools are perceived considering their context of implementation.

The quantitative survey, despite its statistical limitations, underlines the low adoption rate of parametric modeling tools and the concerns architects have about these design support tools. These architects, according to their capacity to act and to the set of constraints they evolve into, are ready to explore how parametric modeling tools contribute to improve the workflow, better adapted to their expectations and creativity (Riccobono & Pellitteri, 2014; Terzidis, 2004). This approach highlights the potential reconfiguration of modes of action in reference to the relationships that these technologies imply.

Finally, research addressing digital transition has mainly focused on the development of tools, and not on the fine-grained understanding of the adoption phenomenon. This study delineates some of the barriers and enablers impacting the adoption of parametric modeling in SME's. The concerns that architects might express through the in-depth interviews (and considering their potential bias) might possibly reshape the workflows and models underlining the early phases of their architectural design processes. Emotions and feelings of the (non-)adopters might shape their relationships to the technology. Although outside the scope of this paper, this constitutes an interesting path for future research. The consideration of these apprehensions is essential, if one aims to avoid the development of technologies that are not suitable to day-to-day realities of architectural SME's, and not sustainable in the long-run.

Questioning the architectural field at a key moment in its digital transition, this contribution articulates knowledge of emerging practices and methodological results. It is part of research that questions emerging practices in the light of new technologies, whatever these practices (whether parametric or non-parametric; parametrically stable or unstable) and technologies may be. In that regard, the paper articulates theories of technological determinism and socio-materiality as two complementary viewpoints, by addressing the impact of an emerging technology from an end-user perspective.

Tables of captions

Table 1. Size distribution of firms in Belgium, considering the survey sample (N= 572).

Figure 1. An algorithmic chain and its geometric representation.

Figure 2. Interest rate for parametric tools depending on the size of the offices (N= 376).

Figure 3. Approaches for the implementation of parametrics in SME's, with regard to the expertise profile.

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