How Do Small and Medium Architectural Firms Deal with Architectural Complexity? A Look Into Digital Practices

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Digital design tools are nowadays deeply rooted in most architectural design processes. Either used as a way to communicate a designed artifact, or rather as a medium to test innovative morphologies (lately referred to as non-standard architecture), these design tools profoundly shape the way architects envision complexity all along their day-to-day tasks. The large teams of "star-architects" were able to develop dedicated and specific strategies and digital tools to overcome some of the technological gaps they were faced to when using commercial packages. But how are small and medium firms dealing with the inherent complexities of such software? This contribution analyzes how those firms (and more specifically the Walloon ones) deal with the growing complexity of digital tools, both in terms of use and interdisciplinarity.

Keywords: *Digital design support tools, architectural practice , non-standard architecture, architectural complexity, small and medium architectural firms*

INTRODUCTION

First introduced as a substitute for hand-drawing tools, digital design tools are currently used as a way to innovate, notably in terms of architectural morphology. Enabling the development of new - and more complex - morphologies, these design tools are also partly responsible for the growing complexity of the design process itself.

Historically architects have raised questions concerning their design tools, mostly about their relevance and impact at different stages of the design process. Regarding these new-generation design tools, issues first emerged because of the overall complexity of the software themselves: difficult to master, the misunderstanding lied both in regard of their very underlying logic and their unfriendly user interfaces. Architects therefore began to develop strategies to go beyond these difficulties and slowly recover consistency in their processes.

"Star-architects", with their large multidisciplinary teams, were of course able to develop dedicated and specific digital tools to overcome some of the technological gaps (Shelden 2002): one automatically thinks about Franck Gehry and his "CATIA teams" of software engineers, for instance. This paper rather looks into the habits and strategies adopted by small and medium architectural firms. Which steps and mechanisms of the design process

have been influenced by the use of digital tools? What are the commonly used software packages, and how do designers adapt to master them? How are those small and medium firms dealing with the inherent complexities of those commercial software? What impact does digital design have on teams, and what kind of digital expertise is expected nowadays?

The paper first discusses new forms of complexity reflecting current architecture practice, and investigates how complexity takes roots through the digital medium. The contribution then describes and analyzes the situation of small and medium Belgian offices, reflecting particularly on the way architects implement and take advantage of digital tools when designing architecture.

STATE OF ART

The development of digital design tools has introduced a big shift in architectural morphological approaches, fostering the growth of what is today known as "non-standard architecture" (Migayrou 2003). More than the digitization of traditional representations, numerical modeling has transformed both the formal vocabulary and architectural thinking by considering and modeling other factors influencing the shape (spatial, societal, aesthetic), generating possibilities better suited to the renewed expectations of some architects. This digital turn was illustrated by the "Non-standard Architecture" exhibition organized by Migayrou in 2003 at the Pompidou Center in France. He also curated another exhibition, called "Naturalizing Architecture", milestone event for the second digital turn, driven by theories of complexity and by new digital technologies (Artemel 2015).

Non-standard architecture has left many projects at their virtual, embryonic stage. The supposed freedom left to architects to design innovative shapes would indeed, as a consequence, rather introduce a complexity in terms of building them. However, built projects such as the Guggenheim Museum in Bilbao, for instance, pave the way for a renewed vision of feasibility shadowing the evolution of materials and digital manufacturing possibilities. They displace the traditional issues of complexity in terms of form and structure and bridge the gap between the thinkable and the buildable (Monier and al. 2012).

The meaning of complexity itself has changed in regard of design methodologies used at different times as well as in regard of available resources. To understand these evolving levels of complexity in architecture, it is interesting to look into the work of the French philosopher Edgar Morin, who highlighted the emergence of complexity in general as a new paradigm, renewing our relation to the world. Considering this notion of complexity, we mention here some studies that define the limits of this concept. Corning (1998) defines the properties that are commonly associated to the term rather than defining the term itself. Three attributes are often implied: (1) a complex phenomenon consists of many parts (or items, or units, or individuals); (2) there are many relationships/interactions among those parts; and (3) the parts produce combined effects (synergies) that are not easily predicted and may often be novel, unexpected, even surprising. To focus more deeply on architectural field, a research by Chase and Murt (2000) mentions two notions of complexity to take into account: the design complexity, based on visible features of the designed object; and the CAD complexity, based on the actual CAD embodiment of the design.

A THEORETICAL LOOK INTO COMPLEXITY THROUGH HISTORY OF ARCHITECTURE

These theoretical contributions taken into account, this section deepens the notion of complexity in architecture in light of three different 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.

Morphogenesis through experimentation

In the past, understanding and controlling morphogenesis of structures, often inspired by nature, usu-

ally 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 and al. 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, while providing a visual simplicity and coherency, still generated complexity in terms of mathematical description of the shape and transfer to reality.

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. Then a new generation of tools (such as parametric software) started to impact more deeply the design process. These design tools gave a wider number of shape possibilities, leading to the non-standard architecture introduced above.

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. This software, initially supposed to simplify the design process, rather generated multiple levels of complexity. We sum up these levels through three main ruptures partly explaining why lots of these complex shapes remained at this virtual stage (Picon 2010; Stals and al. 2015). The first rupture takes place between morphology and structure: the digital approach rather encourages erasing the structure at the benefit of morphological audacity. The second one appears at the interface of multidisciplinary skills and knowledge of the design process, while the third rupture operates at a scale and tectonic level of the project. All these ruptures lead to tensions between architectural desires and technological potentialities.

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 do push forward the possibilities offered by digital tools. The attitudes of architects are consequently slowly evolving. Some of them realize that the introduction of digital tools into the design process enables more than simply processing information: they are therefore ready to explore how these tools might contribute to the development of innovative morphologies, better adapted to their expectations and creativity. By doing so, they still have to address the above-mentioned complexities and ruptures, and they tend to develop protocols and strategies. While large architectural firms have developed their own research and development teams, and even their own proprietary software, little is known about the strategies adopted by small and medium architectural firms.

A LOOK INTO BELGIAN PRACTICES

Digital tools are presently recognized for their potential to develop new complex, non-standard architecture. But how do small and medium architectural offices deal with those digital tools? Do they achieve such breakthrough as easily? The paper reports findings from the current situation of Belgian offices, more specifically about the challenges they face in dealing with digital tools during their design process, and about their perception of complexity all along this process. Within this research, Wallonia (the south part of the country) is a perfect case study because it is known to be dotted with quite small offices.

Research gap

Following up existing literature, we understand that a gap of knowledge exists when it comes to current architectural practices in small and medium offices. A significant amount of work is done about large architectural firms, such as Shelden (2002) focusing on Gehry's architecture. More specifically in

Belgium, the last study about the use of digital tools by architects was conducted in 2008 (Weytjens and al. 2008). 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 digital tools in architectural practices. It rather classified six types of design tools according to the role they played all along the design process: knowledge - based tools, communication tools, modeling tools, presentation tools, structuring tools and evaluation & analysis tools. Researchers observed that the use of DSTs was important in the architectural design process, and indicated an increasing use in the future. The results stressed the importance of a clearer understanding of users' needs, and notably pointed out that CAD-software was merely used as a presentation and modeling tool.

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

- How do architects use digital tools nowadays in Wallonia? Do they express interest for new technologies and software, supposedly helpful when designing non-standard architecture?
- Where does the day-to-day complexity hides, according to Walloon actors of architectural design? What are the factors and actors who make their work more complex?
- What challenges do they face when using digital tools? Are those challenges considered as building up current architectural complexity?

Methodology

Regarding the large amount of people to reach (about 13.000 architects or architectural engineers), we used an online-based survey strategy in order to explore the previous research questions. The following sections aim at developing the methodology used to rigorously build and analyze this survey.

The questionnaire was built around three main sections. The first part began with 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 and most important section questioned designers' digital culture, the digital tools they use, their feelings about those digital tools and the impact those digital tools have on the architectural design process, from their point of view. It also formulated specific questions about complexity, such as "List here the 5 main factors that, from your point of view, make your current practice more complex?" or "Do you think digital tools make your current practice more complex?". This section contained 26 questions with 6 open-ended questions, 10 semi-open questions and 10 closed-ended questions. The concluding sections investigated parametric design and tools.

The survey was tested with a first round of a few participants, which enabled us to specify the meaning of some questions, to adapt some fixed-alternatives answers and to test how much time was needed to complete the questionnaire rigorously.

If a completed survey fulfilled one of the next 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 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, and therefore offered no data about digital or parametric design/tools. This means that some surveys, where only a few questions had been dismissed, were still considered as valuable (in that case, a "no answer" - NA 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 or included in larger, contractors structures.

Sample description

The survey was addressed to all Belgian architects and architectural engineers, and has covered more specific topics, including parametric design and parametric tools, as previously stated. Given the specific scope of this paper, we will concentrate here on the data provided by architects working in the Walloon part of Belgium (where most of the small and medium architectural firms are settled) and we will more specifically focus on topics related to digital tools and architects' perception of complexity. This first exploration of the data mostly concentrates on quantitative results basically treated in order to delineate general trends, and supported by qualitative data to more closely look at some of these trends.

After cleaning the data, 331 surveys were treated for this research, representing 6.2% of architects registered to the French and German-speaking Architects Association. The female-male parity is close to data already collected by this Association, in regard of a previous survey conducted in 2013 (66% male architects at that time, Tchinda 2013). In our case, 73.4% of the surveys are answered by men and 26.0% by women (while 0.6% did prefer not to answer), indicating that the current sample is sufficiently representative of the Walloon population. 49.8% of the participants are under 40 years old, confirming the relative youth of the population as already observed by the 2013 survey. 34.2% of the respondents are practicing their main occupation for more than 20 years and 23.5% are practicing it for 10 to 20 years. Regarding their main function, 56.3% of the respondents are isolated, independent architects (working on their behalf), 10.5% are independent architects working for some collaborator, while 6.4% are architectural engineers and 4.7% are teachers (other participants distribute among other occupations). Throughout this paper we will refer to the participants as "designers".

Figure 1 demonstrates the relevance of the Walloon case, since 41% of the respondents are working in a firm of only one or two people. Furthermore, 73% of the participants are working in a structure smaller than 10 people.

Figure 1
Size distribution of firms in Wallonia.

Size of firms (number of people)	1 to 2	3 to 5	6 to 10	10 to 20
Percentage	41,0%	21,4%	10,6%	9,6%
Size of firms (number of people)	20 to 50	50 to 100	> 100	Other
Percentage	4,0%	4,0%	6,2%	3,1%

RESULTS

Use of digital design tools in Wallonia

Our results first show that 72.5% of the participants indeed use digital tools during the design phase. Figure 2 moreover shows that designers using design tools just for 2D drawing mainly use AutoCAD (55.9%), followed by ArchiCAD (17.6%) and Vectorworks (15.1%). ArchiCAD is also used as a 3D support tool (24.5%) but Sketchup remains the reference for 3D modeling in architectural design, at least for 50.3% of the users. Parametric software such as Grasshopper, Generative Component, Vasari or Digital Project are either totally, or largely unknown by the Walloon population. Revit, however, deserves a closer look: our results show that it is generally used in 3D rather than in 2D. Revit is mainly used by designers under 45, with a peak for the range 31-35 years. It is also more often referred to by offices counting more than 20 employees, representing only 14.2% of the Walloons designers (Figure 1).

Looking at how designers integrate digital tools to their everyday practices (the 102 "NA" answers put aside, that is almost one third of the respondents), our results show that 49.5% of them are autodidacts, learning thanks to tutorials or forums, asking their better trained colleagues for some help. 31.5% learned either at school, through additional training or through on-the-job training. Another 9.7% hire experienced employees to whom they can either delegate some work, or ask for some help when they

want to improve their own skills. Another interesting trend is that around 9% of designers implement working protocols (such as using layers, pre-defined templates, ...) to streamline and standardize their process. This strategy is usually implemented after having completed training or thanks to the input of newly hired, experienced employees.

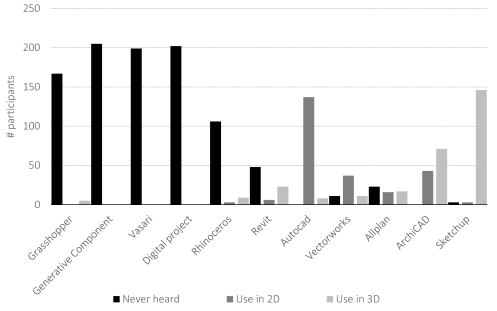

Figure 2
Knowledge levels and use of digital tools in architecture.

The survey moreover offered the participants to comment about the aspects and features of software they appreciate or not. Some designers comment that "the project can be quickly modelled in 3D" thanks to digital design tools, particularly through data libraries, and that there are easy ways to "use only one software to make the 2D and 3D simultaneously". Another advantage of digital tools is that "changes are easier to perform without much costs (time, energy)". The 3D model also enables them to "check the impact of architectural choices" and "urban integration", while getting a better understanding of the client and the administration. In this regard, the software enables "faster exchanges" with partners, outside and inside the office (as we will discuss later). While some Walloons highlight the advantages of tools integrating BIM, others still see these tools as the simple "extension of their drawing board".

Among the most common negative aspects reported by participants, the fact that there are "too many tools available" is considered as a challenge in terms of day-to-day workflow. The "expensive price of software", "too frequent updates" that require "counterproductive adjustment periods" and the "growing burden" of purchasing new computer equipment are moreover frequently referred to. Some raise the fact they spend "too much time working on it", one of the reason being that digital tools push to "draw too precisely from the sketch on". Another criteria considered important is that "complex shapes are difficult to represent" (e.g., curves) and that producing a "non-standard element is complex", generating "less creativity".

Complexity and the use of digital design tools

The large proportion of designers using digital tools (72.5%) first of all 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, 23.7% of the designers aged 55 and more indeed declaring not using any digital tool, comparing to the 5.5% younger than 55 years old who do not use digital tools.

84.6% of the respondents are satisfied with the digital tools they use. 58.2% of them are not only satisfied but consider that the digital tools do not make their work more complex. That leaves 15.4% of surveyed designers unsatisfied, while 23.4% find that digital tools have made their work more complex in general (other respondents do not have a strong opinion). Digital tools are indeed among the top six factors that make nowadays architectural practice more complicated, side by side with administrative formalities; regulations (and more specifically planning regulations), "PEB" certification (Belgian building energy efficiency certification), evolving building techniques and customer requests. Some of these criteria were already mentioned by the Flanders study conducted in 2008 (Weytjens and al. 2008). This study, that more specifically researched the various parameters taken into account when making design decisions, underlined professional experience as the most important factor (86%), closely followed by the client's demands (76%). Almost 60% of the respondents at that time said they made design decisions based on regulations, while only 21% of them

included design support tools as a decision-making factor. Comparing both studies, we can therefore suggest that the factors influencing decision-making processes in design are partly similar to the factors making the design process more complicated.

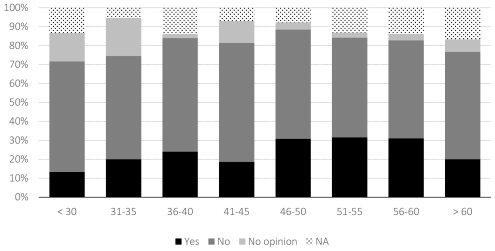

Figure 3
Growing complexity of architect's work with the advent of digital tools, in regard with age.

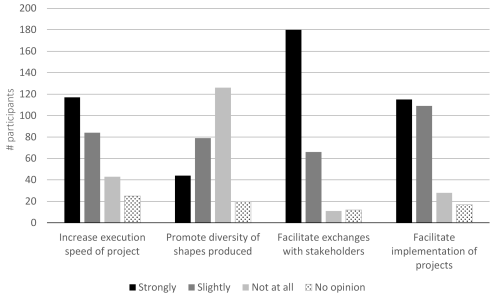

Figure 4
Influence of the digital tools on diverse pre-defined parameters.

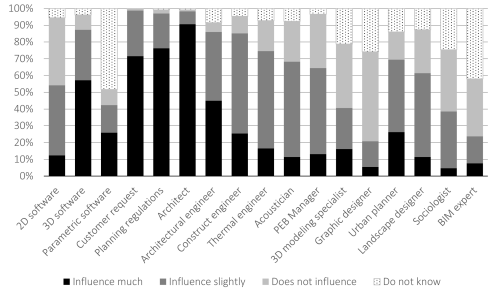

Figure 5
Factors and actors influencing the produced and designed shape.

Figure 3 shows that the perception of complexity in architecture globally increases with age. A generation effect is nevertheless observed for the age group 41-45. 62.8% of them 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. A similar effect is observed for people older than 60 years (58.6%). As a side note, one of the participants commented: *"All in all, the computer is magical for those who began drawing by hand"*.

Beyond this noticeable complexity, digital tools have strongly increased the execution speed of projects, strongly facilitated exchanges with stakeholders and also strongly facilitated the implementation of projects (Figure 4, 62 No Answer hidden). Moreover, 78% of the contributors consider numerical modeling as enriching the design of an architectural project.

The impact of digital tools on current Wallonia architectural practices is moreover illustrated in Figure 5. Again, for clarification, the 92 respondents who skipped this question have been hidden (92 "NA"). This chart resumes which pre-defined factors and actors are considered as mostly influencing the designed shape. Planning regulations and customer demands are again considered important influencing criteria. 3D software is the 4th most influencing factor when it comes to architectural morphology, according to the surveyed designers.

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. They rather agree (57.3%) that digital tools have modified their control over the implementation of the project, and at the same time did not improve control of building costs. These trends are not influenced by the designers' age or professional expertise, but are influenced by the size of the firm. The designer's intention, control over implementation and control over costs are indeed proportionally considered as more deeply impacted by digital tools as the size of the firm increases.

Complexity into interdisciplinarity

It is nowadays largely accepted that design processes do integrate more and more stakeholders. 54.8%

of the respondents consider time as the main factor pushing them to outsource tasks. The complexity of the shape is the next reason to externalize some design tasks, at least for 24.4% of the designers. In fact designers a larger proportion of designers (57.1%) agree that interdisciplinarity is totally beneficial to the project, but still assert that this interdisciplinarity is difficult to manage it humanely speaking (for 51.1% of the respondents - 108 NA removed) and technically speaking (50.2% - 108 NA removed). Walloon designers consider that the digital tools have strongly facilitated the exchange with stakeholders (Figure 4). Looking more closely at these exchanges, Figure 6 reveals that architects rarely outsource the chore steps of ideation (the architect being the most common internal "consultant"), while the building engineer is the most requested external consultant. 3D modeling specialist is more frequently reached out internally (i.e., part of the design team) than externally, showing a close working proximity between him/her and the architect. The graphic designer is slightly more consulted externally than internally, showing that the proximity between the two professions is less important. Moreover, 3D modeling specialists are approximately 50% more consulted internally than graphic designers. This trend is already illustrated in the Figure 4: 3D modeling specialists are considered as having more influence on the designed shape than graphic designers. All these observations are supported by another result: 49.5% of the architects consider numerical modeling as enriching the design of an architectural project, even when this task is not assigned to the person who primarily designed the project. Qualitative information help us to better understand this result: we have to distinguish architects who consider 3D modelization as part of the design process itself from architects considering 3D models useful only to produce "commercial" images. When outsourcing the task, architects from the first group generally rely on 3D modeling specialists considered as close colleagues to work with. Some of them comment: "modeling is part of the design process and evolves with it in an iterative process". Architects from the second group, on the other hand, rather resort to graphic designers working remotely. Some of them recognize that entrusting some external consultant with the 3D modeling task might be interesting: "different points of view, ideas or advices are always welcome"; "architects cannot assume everything anymore" and have to learn to "delegate by giving the good information" and through "regular exchanges".

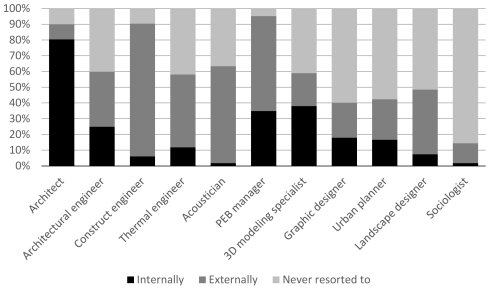

Figure 6
Comparison of stakeholders consulted internally or externally

DISCUSSION

Our first research topic was concerned with the current use and perception of digital tools in Wallonia, where firms are mostly of small and medium size. Our results underlined that architects are globally satisfied with their digital design tools since they mostly consider them as a faster way to process a project, compared to drawing it by hand. They do not currently work a lot with complex 3D or parametric tools, and feel remote from these new design support tools considered as designed for - and more adapted to - larger offices working larger-scale projects. Yet, when expressing some interest, one has to observe that architects do not hesitate to slowly master software as autodidacts, with the help of tutorials and close or freshly hired colleagues. Few of them do implement working strategies and protocols specifically related to the use of digital tools.

While digital technologies have freed architectural innovation for star-architects while producing several layers of intricate morphological complexi-

ties, small and medium architectural firms deal with other levels of day-to-day challenges, dependent of the architect's level of expertise and size of firm. In Wallonia, the complexity does not seem to lie in the expression of the designed shape, but rather in the down-to-earth use of digital tools. While 58.2% consider that digital tools simplify their processes, the multiplicity of available tools and the difficulty to remain up to speed with evolving software (both on financial and timing aspects) distance them from further possibilities these new generation design tools have to offer.

When faced with difficulties, close to 25% of the architects do not hesitate to outsource the 3D modeling task, while being aware of both the positive and negative effects such outsourcing might have on the design process and output. Some of them consider 3D modeling as part of the design process itself: those do prefer to keep the digital phase under control, therefore entrusting the task to some close colleague(s). Others see in 3D modeling nothing else than a way to generate nice-looking pictures.

Our results eventually shed light on the significant gap existing between theoretical models of complexity mentioned in literature review, and how complexity is considered, day-to-day, on the field of small and medium architectural firms. While complexity may indeed lie in the design of innovative morphologies for larger architectural firms, it rather hides inside administrative procedures, regulations, building techniques and customers requests for small and medium ones.

Before unveiling other layers of design complexity to small and medium architectural firms, one has thus first to acknowledge down-to-earth, day-to-day operational challenges. Only then, architects will be able to afford renewed thinking about what digital design tools have to offer in terms of architectural innovation.

FUTURE WORK AND CONCLUSION

This paper looked into the challenges architects working in small and medium firms face when dealing with digital tools during their design processes. It underlines how their perception of complexity all along their day-to-day practices diverge from the current trends discussed in literature review, especially in regard to larger architectural firms.

Future work will concentrate on two areas. Firstly, more data has to be retrieved in order to test, and eventually validate and amplify the trends already identified in this paper. This data will cover the entire country and may refine results in regard of digital culture and size of architectural firms. Secondly, the part of the survey concerning the use of parametric design and tools will be investigated. Thirdly, we will deepen our understanding of current working strategies by interviewing selected offices that answered positively to the possibility of further contact and on-field observation. This final phase will help us raising awareness amongst small and medium offices tabout new digital design tools, researching whether we should help Belgian designers adapting their processes or rather push for software adaptations.

REFERENCES

Artemel, A. J 2015 'Q&A: Mario Carpo on Architecture's Digital Past and Present', *Metropolis - www.metropolismag.com*

Blumenthal, M 1971 '« Introduction », Techniques et Architecture', *Special number Informatique et architecture, no 4, 33e série*, p. 33

Bourbonnais, S 2015, *Sensibilités technologiques : expérimentations et explorations en architecture numérique 1987-2010*, Ph.D. Thesis, Université Paris-Est

Chase, S and Murt, P 2000 'Evaluating the complexity of CAD models as a measure for student assessment', *ACADIA 2000: Eternity, Infinity ans Virtuality*

Corning, P 1998, *Complexity is just a Word ! In Technological and Social Change*, Elsevier

Migayrou, F and Zeynep, M 2003, *Architectures non standard*, Centre Pompidou, Paris

Monier, V, Duchanois, G and Bignon, J-C 2012 'Génération de formes non-standards au moyen d'éléments natifs irréguliers en bois – Elaboration d'un outil numérique de conception architecturale', *SCAN 12 : Complexité(s) des modèles de l'architecture numérique*

Picon, A 2010, *Culture numérique et architecture*, Birkhäuser, Bâle

Shelden, D 2002, *Digital Surface Representation and the Constructibility of Gehry's Architecture*, Ph.D. Thesis, Masachusetts Institute of Technology
Stals, A, Elsen, C and Jancart, J 2015 'Challenges in teaching architectural morphogenesis', *Proceedings of the 3rd International Conference for Design Education Researchers*, Chicago
Tchinda, C 2013 'Rapport d'enquête : conditions de travail des architectes', *Unpublished report conducted by French and German-speaking Architects Association*
Weytjens, L, Verdonck, E and Verbeeck, G 2008 'Classification and Use of Design Tools: The Roles of Tools in the Architectural Design Process', *Design Principles and Practices: an International Journal*