The interfaces between technologies and the design process in AEC industry

Paola Zardo[1], Andréa Quadrado Mussi[2], Juliano Lima da Silva[3]
[1,2,3]Faculdade Meridional (IMED)
[1]pazardo@gmail.com [2,3]{andrea.mussi|juliano.silva}@imed.edu.br

This is an exploratory study that had the purpose of understanding how Building Information Modeling (BIM), parametric design and digital fabrication are adopted in Architectural, Engineering and Construction (AEC) design processes and how they unfold through and influence its stages and activities. Questionnaires and interviews were performed with professionals from or with previous experiences in firms considered to be early adopters of digital technologies in practice. Results suggest that the addressed digital technologies have complementary functions and can improve each other's potentialities when integrated in design process' stages. Their performance can also be improved when achieving a more holistic process, embracing constant feedback loops through parties involved and design solutions throughout its stages. In order to have this approach in overall AEC industry, many transformations are needed and some of them were also pointed out in this study.

Keywords: *Digital Technologies, Design Process*

INTRODUCTION

Digital technologies, such as BIM, parametric modeling and digital fabrication, which are the subjects of this study, bring the computer as a much less neutral element than it was in Computer Aided Design (CAD) era, when it was adopted merely as a tool to reproduce manual work of representation (Aish and Bredella 2017). Differently from that, the computer now becomes an ally of designers in producing design solutions at the same time that it expands the possibilities not only for design exploration but also for production. This new, not only instrumental idea of digital contexts ends up demanding and provoking transformations to design process as well, once the latter becomes influenced by the new approaches to design process. To achieve a chain of automated processes from design to construction, reaching the possibilities of digital technologies in depth, it is necessary to make room for the ever-present interdisciplinary approach of construction industry in a holistic and non-fragmented manner and therefore to adopt non-fragmented processes (Bernstein 2012).

Although there are many publications about possible applications of each of these digital technologies in design process, the questions relate to how their applications are actually consolidated in professional practice and what are the interrelations between them within the procedural complexity that accompanies them. It is known that the absolute adoption of digital technologies in firms is more exception than rule in overall AEC industry, either because not all practitioners or firms have access to these technologies, or due to the resistance in adopting them. However, as Cross (2007) establishes about outstanding designers, experiences of early adopters, who instantiate the paradigm shift and often foster change in AEC industry, can give us projections on what to expect. This was the direction taken for the development of this study, that aims at understanding how digital technologies are used and the possible effects of their adoption in design processes' characteristics, based on different professionals' points of view.

METHODOLOGY

Data collection

Firstly, a review of publications was performed and allowed the authors to identify seventeen companies from different countries that outstand as early adopters of digital technologies. In general, these are global practices that usually work on larger scale and investment projects. Subsequently, through professional network and e-mail, professionals who work or have previous experiences in these companies were invited to participate by filling a semi-structured online questionnaire. More than two hundred professionals were contacted, however, only thirty provided responses that will be analyzed in this paper. According to preferences of some participants, the online questionnaire was replaced by videoconference interviews in their cases.

In order to compile different perspectives, no position criteria were applied on beforehand. The sampling strategies used were by accessibility or convenience (Gil 2008), as well as snowball sampling, since some participants indicated other professionals who could contribute to the study. Participants are based in different countries, but mainly European countries and the United States. Regarding their positions, there were: managers, project coordinators and BIM coordinators/managers (10), designers (8), architects (6), directors (5), engineers (3) and consultants (3), some of which simultaneously assume more than one function.

The design process definition adopted for this study, based on the definition by Fabricio (2002), involves all decisions and formulations aimed at subsidizing the creation and production of a project. Therefore, it is not only about the creative process from early design stages, it also includes the interdisciplinary design development, construction documentation, as well as construction and operation stages, which are subsidized by design decisions and sometimes require changes in them.

The questionnaire contains questions regarding the applications of BIM, parametric modeling and digital fabrication, as well as regarding the flow of activities developed in the stages of design process. These are: descriptive questions about the flow of design process, its stages and activities performed in each stage, software used and agents' involvement through process stages; plus three multiple choice questions about the main applications of BIM, parametric modeling and digital fabrication, respectively, with alternatives elaborated based on previous bibliographical studies about the use of technology in practice. In these questions, professionals could select more than one alternative for each and also provide additional comments through an "Others" section. Regarding the descriptive questions, in order to focus on the use of digital technologies in real world projects, participants were asked to provide responses considering the most digital design process they have ever been part of.

Qualitative analysis

The collected data were analyzed by using the Computer Aided Qualitative Data Analysis Software (CAQDAS) MAXQDA. The textual documents containing the questionnaire responses and the transcripts of the interviews conducted by videoconference went through coding in order to perform data reduction.

Codes related to the main thematic axes dealt with in the questionnaire were created: stages and flow of the design process; involved agents and their functions; software and their main applications; coordination, communication and sharing. Then, based on the individual analysis of each code's results, new sub categories were created in order to perform new coding rounds.

Stages were named in many different ways by the participants while describing them. Due do that, a design process reference model, elaborated based on the compilation of different bibliographical and documental sources (Melhado 1994; ABNT 1995; Tzortzopoulos 1999; AIA 2007; Succar 2009; Eastman et al. 2011; RIBA 2013), which could be compared to the descriptions provided by the participants, was used in order to organize the described activities in separate stages. Thus, the following division in eight stages was considered: Criteria and Constraints, Concept Design, Schematic Design, Design Development, Construction Documentation, Review and Bidding, Construction, and Operation.

Subcodes were also created for each software mentioned, for listed agents, activities related to coordination, and for the communication and sharing resources reported to be used. The analysis of co-occurrences and code frequencies made possible by CAQDAS provided new insights to the analysis and guided the presentation of the results.

Despite the variability of positions, companies and countries of the participants involved in this research, it is important to highlight that the authors analyzed the point of view of a restricted sample of professionals, which may not represent the majority on a global scale, given the limitations of the sampling techniques used. However, this is an exploratory study and its highlights are the fact that the discussions include diverse perspectives, from participants with origins in different parts of the world, as well as that it deals with BIM, parametric design and digital fabrication altogether and not separately.

RESULTS AND DISCUSSIONS

The contemporary design process

The summary of the design process' stages, containing the activities of each stage according to the descriptions provided by the participants, is presented in Figure 1. A strong presence of digital design methods and tools can be observed, which was expected, since participants were asked to describe the most digital process they have ever been part of, in order to focus on digital transformations.

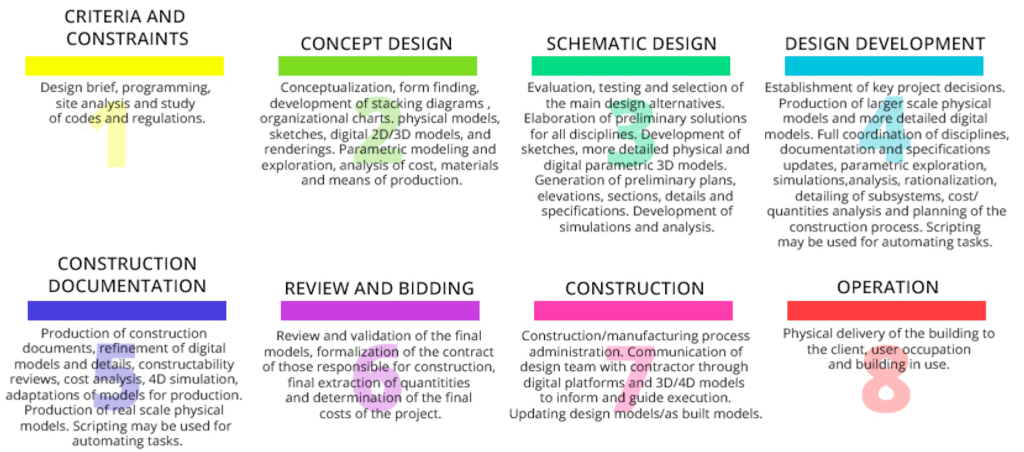


Figure 1
Summary of descriptions of design process' stages and activities from responses.

According to the results presented, digital models can be considered central artifacts of design activities, that guide decision-making and are progressively being developed over the stages, acquiring new information and becoming increasingly detailed and complex at the same time. Despite this, it is important to highlight that digital methods and tools are not necessarily completely substituting traditional ones, since sketches and diagrams, for example, still play a significant role in design activity (see Figure 1). Physical models were used for a long time in design process and still are, but now they can be produced by digital fabrication methods. Therefore, what happens in the contemporary design process is an evolution and integration of different methods that complement each other and open up new possibilities to meet the growing demands of AEC industry, which are, simultaneously, according to Deutsch (2017): speed, feasibility and quality.

This leads us to two different issues that have to be remarked. First, this whole context of digital tools and features eventually brings challenges to designers in overall AEC industry regarding the necessity of developing new skills and competencies, including and especially ones related to the management of the expressive amount of data that is now generated through digital design technologies. At the same time, everything needs to be integrated so that this complex contemporary design process works efficiently. In this sense, the traditionally high levels of fragmentation between activities and products from different design disciplines in overall AEC industry are becoming impractical and unfeasible.

The design of a building was not ever simple. Buildings are complex structures, composed by many different disciplines and elements. Add a whole new world of artifacts and embedded design data to this already great complexity. It becomes clear that transformations in design process are needed in order for that to work properly. This complex context that accompanies digital technologies may be routine in some global AEC firms (the early adopters), but in the rest of the industry, it can be extremely confusing and even detrimental to their productivity and results.

Regarding the need for integration in different facets of design process, other results of this study should be analyzed. Participants reported to have observed different ways of conducing the design process in practice, with several forms of negotiations between parties involved in order to incorporate feedbacks to design solutions along design process' stages.

As one of these possibilities, some of them mentioned the pre-establishment of milestones before the beginning of the project to forecast breakpoints and reviews in order to incorporate feedbacks from others involved, conditioned to the approval of certain parties. The main functions of these predetermined loops were reported to be related to review of issues such as constructability, cost, efficiency, coordination, performance of the project and the means of production. According to the respondents, in addition to these items of technical and economic bias, feedback is primarily intended to incorporate the opinion of the client/owner and to get their approval. Many of them also highlighted that a participative behavior of the client during design process is extremely important to project results.

The prediction of breaking points in process' stages for clients or other designers' reviews does not necessarily imply an effective and ideal integration. However, more integrated and iterative approaches of conducing design process were also reported, referring to the constant analysis of previously mentioned aspects (such as constructability and costs) since early concept design stages, in order to optimize design solutions and reduce possible problems and rework. In these cases, digital technologies were pointed out by the participants as playing a fundamental role for enabling and fomenting these iterations, considering its simulation and optimization features, as well as the possibilities of having more transparent flows of data. However, they also pointed out the difficulties in changing other parties' mindset to this open information approach, some of which were presented in a previous publication of early results of this research project (Zardo and Mussi 2018).

Also, some participants mentioned that the type of contract can limit or extend designers' involvement in a project. This inevitably will influence their comprehension of what the design process embraces, which tends to cover the main stages they participate in. Therefore, in line with the need for greater integration in contemporary design process, giving space to more flexible and integrative types of contract can help in reducing the procedural complexity that hinders the insertion of technology in most of AEC firms.

As it's possible to see in Figure 1, operation stage was only briefly described by participants and no mention was made to the use of digital technologies at this point, although there are many publications about post-occupancy evaluation and facilities management with the use of digital models in academia. This may have been due to the fact that this stage is sometimes not embedded in designers' belief of what the design process encompasses, but also suggests that this needs to be further explored to complete the cycle of digital technologies and for not only designers but also users to achieve all of its possibilities.

Tools and technologies in design process' stages

The increasing complexity of the contemporary AEC design process extends to the amount of tools available. In terms of software, a myriad of products were listed by the participants. There is a whole ecosystem of them related to BIM, parametric design and digital fabrication available for building designers, with complementary functions, so not only are there many available, but many are used for the same project. Holzer (2015) also reports how different tools are progressively converging in architectural design studio, focusing on the relationships between geometric exploration and building performance, which is just one of the many examples of how integrating different tools can improve design solutions. The main software reported by professionals are, according to their different categories of applications:

Sharing Data, Communicating, Managing Information and Tasks: New Forma, A360/BIM 360, Bluebeam RevU, Aconex, Teamwork Projects, Trimble Connect, Athena, ProjectWise.

3D Modeling: Rhinoceros, SketchUp, Maya, Geomagic, Zbrush.

Parametric Modeling and Visual Programming: Rhinoceros, Grasshopper, Maya and Dynamo.

Presentation/Visualization: Rhinoceros, SketchUp, 3Ds Max, Illustrator, Enscape, Adobe Suite, Photoshop, Lumion, Maya, Powerpoint, InDesign and Navisworks.

BIM Modeling: Revit, ArchiCAD, Tekla, Vectorworks, Digital Project.

Coordination: Revit, Navisworks and ArchiCAD.

Specification, Documentation, Detailings, 4D Planning and Fabrication: Vectorworks, ArchiCAD, NBS Create, Tekla, Microstation, Digital Project, Grasshopper, Excel, Revit, Rhinoceros, Synchro, CAD-MEP, Word and AutoCAD.

Programming: Visual Studio.

Simulations and Analysis: Revit, Grasshopper and InfoGraph GmbH.

Rationalization: Rhinoceros and Grasshopper.

Nevertheless, the possibilities become so broad in computational design that sometimes commercial products don't even contemplate functions needed by designers, which demand customized solutions, usually developed through scripting, another new skill that wasn't usually part of traditional design activities and that was also reported by participants (see descriptions of stages 4 and 5 in Figure 1). Moreover, as presented before, tools that were not even created specifically for AEC are being inserted in buildings' design process, such as Maya or Visual Studio, which means designers' scope is expanding with this interdisciplinary digital context.

However, considering that integration in AEC projects is an eminent necessity, this whole ecosystem of tools has to be made easily interoperable in order for many stakeholders to collaborate through different computational design activities, but this is still a hard task. This points out to the needs for improving interoperability in (not only specific) AEC software and highlights why this is a recurrent object of study in publications from the field of CAD.

From a broader perspective, regarding BIM, parametric design and digital fabrication in design process, Figure 2 presents the stages of design process and their presence along them, according to the descriptions of activities, as well as of the main software previously mentioned, organized by order of frequency in responses, which means digital repositories were mentioned the most, followed by Rhinoceros, Revit and so on. Although as built models were reported to be developed using BIM, their use after construction stage was not specified, nor of parametric modeling or digital fabrication.

One important first aspect to be discussed about Figure 2 is the concurrent presence of BIM, parametric design and digital fabrication in most design process stages, which suggest an overlapping/complementary relationship among them. This becomes clearer when analyzing the applications reported by professionals for the three technologies considered in this study, presented in Figure 3, as follows.

Main applications of digital technologies

Besides the ones in Figure 3, professionals also cited as BIM applications: 2D documentation production, project visualizations, and safety analysis. As for parametric modeling, the additional applications are: development of custom tools and BIM objects, and analysis of code/law requirements. There were no additional applications for digital fabrication besides the ones provided in the question.

Regarding the main applications of BIM, it is mainly related to activities from design development and construction documentation stages, such as project coordination, quantities and cost analysis, which are compatible with its strong presence reported for those stages and suggest that BIM is usually inserted in design process after having a well stablished concept design.

However, its third main application according to the respondents (geometric exploration) draws attention for being an activity essentially performed in greater depth during early stages of design process.

There are many discussions about using BIM in concept design stages in publications and presentations, from those that present favorable arguments, such as Garber (2014), to those who discuss its limitations for this purpose. Some limitations, pointed

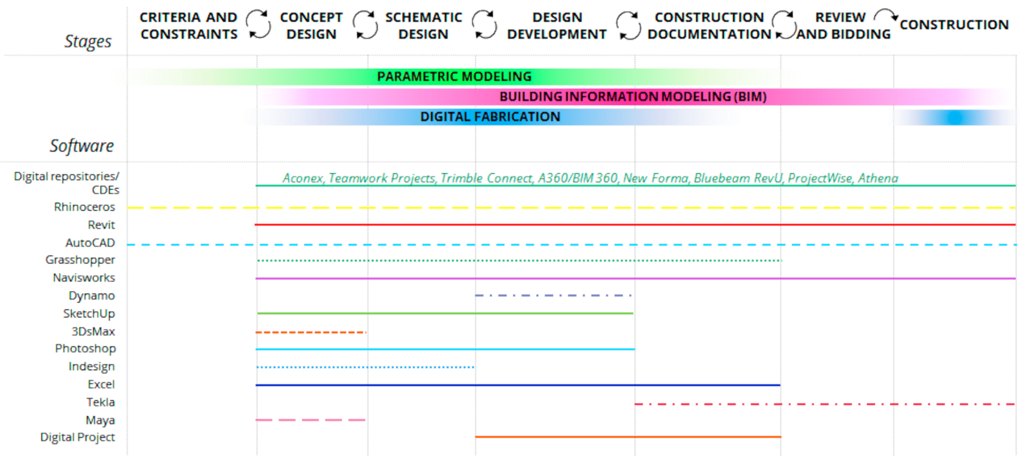
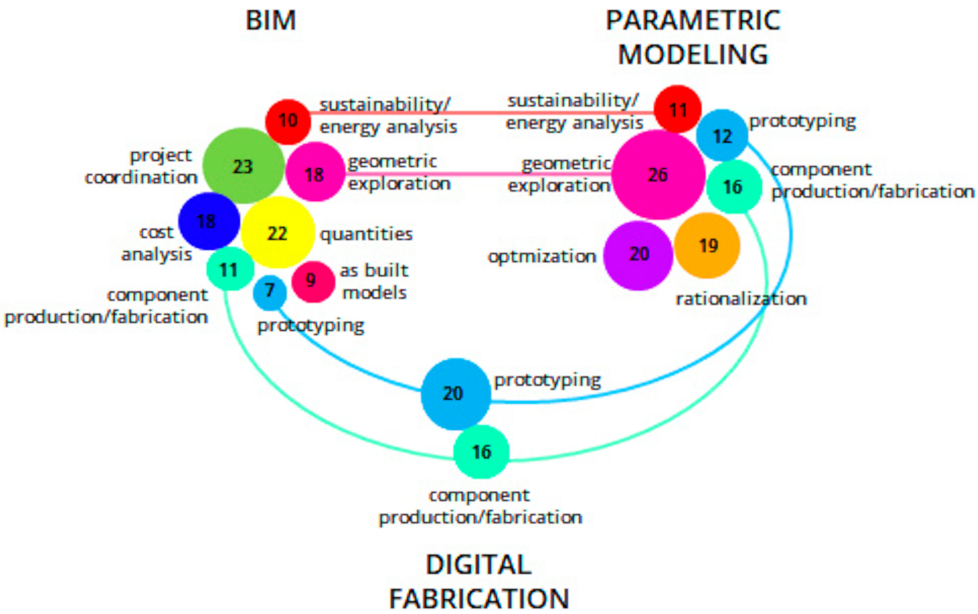


Figure 2
Presence of BIM, parametric modeling and digital fabrication, as well as of the main software pointed out by participants in design process' stages.

Figure 3
Main applications of digital technologies in design process. Circles show the frequency of each application in responses.



out by Robert Aish [1], can be cited as examples, such as the need for thinking in micro ideas (components) before macro ideas (general design solution); the need for precision in BIM models, which is not necessary yet in conceptual stages, when there are still some uncertainties; and the risks of BIM software inhibiting exploration due to the rigidity of information models.

The significant use of BIM for geometric exploration reported may be related to the fact that, in contemporary and digital design processes, analysis of real building data, in attributes of BIM models, are being included in concept design stage. In order for this process of simultaneous geometric exploration and analysis of accurate data to occur, it is necessary to give space for the previously mentioned iterations during the development of design process' activities.

It also should be noted that geometric exploration was reported to be the main application of parametric modeling. This and the other correspondent activities to both technologies support the argument that they complement each other and overlap in the midst of design process. This idea is reinforced by the relationship that can be established between optimization and rationalization, developed through parametric modeling software, and the analysis/simulations based on real characteristics of a building or site in its digital prototype, made possible by compiling BIM models with data attributes and features of parametric modeling tools. Besides that, respondents also mentioned the growing development of customized tools and BIM libraries through visual programming, suggesting that simultaneous adoption may be more appropriate than punctual applications, since one technology can help improving or managing the other.

When it comes to digital fabrication, the situation is similar. Both BIM and parametric modeling have the production of components and prototyping as two of their main applications. So, when combined with digital fabrication, they can allow the development of file-to-factory processes as well as early materialization as a resource for studying design solutions, reducing significantly the historical gap between design and production.

According to the respondents, prototypes are also commonly used to communicate ideas to clients as a visualization resource. The predominance of prototyping over component production may be related to some requirements that are not common in the overall AEC industry, such as millimeter precision in digital models and strict planning of transport and assembly processes, as Scheurer (2012) points out, other aspects that should be reviewed while adopting digital technologies, especially in the case digital fabrication.

In summary, it is possible to argue that the benefits of using digital technologies in design process could be enhanced by their joint adoption. This is not to say that, individually, they do not present benefits. However, joint adoption opens up a new range of potentialities. The process also becomes more holistic since it's not just about adopting a new tool to accomplish a specific objective but about adopting a whole new dynamic that is required to an integrated design process. In this sense, the convergence of technologies ends up reflecting in other aspects of design process, that also start converging. Deutsch (2017) describes this as the convergence era. However, challenges related to the necessary changes are of proportional size, which explains why punctual adoptions of digital technologies predominate in the sector over this ideal holistic process.

Shifts, contrasts and challenges

Design and production, which present a historical gap, with origins in the use of drawings as the main design and documentation feature (Mitchell and McCollough 1995), are becoming closer due to technology. Using digital models that are much clearer to production and construction processes and also using digital fabrication to analyze different materials or to analyze design solutions in different scales, as well as to produce real scale components for onsite assembly inevitably reduces the gap, which reflects in an approximation of design-specific tasks to construction. Due to this, digital technologies not only affect design but also construction and have the potential to affect operation as a result of an overlapping effect in design process' stages.

Moreover, when asked about the agents' involvement, many of the participants said that the design team becomes engaged with contractors during construction and that contractors and subcontractors have active participation in elaborating design details and specifications, so the roles of those involved also start to merge at some point. This contrasts a lot with fragmented processes that are predominant in a huge part of the sector globally, and is possibly a reflex of the adoption of digital methods in AEC industry. As pointed out before, new design methods and technologies make it easier and more feasible to integrate parties and activities.

This integration is accentuated by the use of digital repositories while designing and building a project, or Common Data Environments (CDEs), which are even contemplated in building codes and regulations in the United Kingdom. It is important to highlight that these are not substituting traditional means of communication, such as e-mail or meetings, which were also strongly mentioned in the responses obtained. However, despite many different commercial platforms for this, these repositories allow the parties involved in a project to organize and manage all of the information that is generated through digital technologies, as well as improve the collaboration and communication between stakeholders, thus generating optimized design solutions and project results, so they mark a significant transformation on the way parties relate to each other during design process.

However, reinforcing what was highlighted by participants, there are many challenges to this new dynamic of design process. Besides the new competencies and skills previously mentioned, collaborative thinking, motivation to integrate and share design information (with other designers, consultants and contractors, for example) are extremely important aspects which are not easy to achieve. Regulations such as the ones developed by NBS in the UK also play a fundamental role to organize and make it feasible and accessible to other firms that don't have the flexibility that global practices usually have.

Regarding this, it becomes relevant to highlight that the responses from British participants were highly similar for describing the development of the design process, since most of them follow the same references from RIBA in practice. Having the majority of firms in a country following a similar protocol could make it easier to integrate digital technologies and manage their respective effects in design process thoroughly.

There are many firms and professionals involved in any larger scale project, including ones based in different geographical locations. The understanding of the design process still varies a lot from different localities and different companies, which was already expected in the results of this study, since it involves professionals from many firms and countries. This can make integration and holistic processes a lot harder to achieve. However, when having the same patterns from building regulations being followed at a larger scale than one country, and the support of shared repositories, some of these issues could be more easily handled and strategies could be more easily planned and implemented.

As mentioned before, rigid types of contract also aggravate this scenario. So, besides promoting the development of adequate regulations, bringing flexibility to rooted contract types used could help, giving space to new approaches such as Integrated Project Delivery (IPD), which can form an access road to the holistic design process fostered by the possibilities of digital technologies.

In Brazil, regulations are highly limited and in its initial steps, while fragmentation of design processes, hierarchical work settings and rigid contract configurations still predominate in AEC industry. Also, in general Brazilian AEC industry, even though digital technologies are being gradually inserted in design process, it is in an isolated or punctual manner, not compatible with the processes and possibilities found in the presented results. There are exceptions indeed but the vast majority can fit this scenario. So, in this study, evidences that show the contrast of different realities could be collected in order to highlight and disseminate the need for change in many aspects of the AEC sector.

Although the digital and holistic design process presented along this study is still very restrict to some exceptions worldwide, the results show that there is a reason for that. By changing mindsets, investments, organizations, contracts and teaching it could be possible for it to be expanded in global AEC industry, concurrently to the integrated adoption of BIM, parametric modeling and digital fabrication.

However, process complexity is probably going to grow even more in the next few years, considering that there are other emergent technologies that weren't even subjects of this study, such as Virtual Reality (VR) and Artificial Intelligence (AI), that bring other new possibilities as well as change the way people communicate and operate. Thus, extending the compilation of digital technologies to include the emergent ones can further enhance integration in design process, since they can offer other complementary potentialities to the ones approached in this study.

Therefore, understanding the new dynamics that come with the adoption of digital technologies has to be a constant effort from academia, but it also has to be extended to practice, otherwise they will keep being adopted as mere instruments for punctual functions that don't effectively justify the investments of money and time. Understanding how they unfold through and influence design process' stages can help guiding the major part of AEC sector in this technological insertion trajectory.

CONCLUSION

The results, in summary, suggest and reinforce the idea that digital technologies can drive and intensify the iterations and integration of activities developed during design stages. One of the main conclusions is that technology needs to be used simultaneously and in holistic and integrated processes, as the fragmented adoption tends to maintains the gaps and inefficiencies of fragmented processes, requiring additional efforts that may not be fully compensated in terms of immediate benefits to project results.

However, many changes are needed in order for that to happen smoothly, which are mostly very hard to achieve. This includes changes in the mindsets and way of working by professionals and firms, changes in contracts, promoting patterns for using and integrating so many different technologies, as well as inserting new skills to be developed for future AEC professionals. The lack of these are the possible reasons why digital technologies are commonly misadopted in AEC firms, so understanding how they unfold through process stages is an effort that is needed not only from researches but also in practice.

In the age of the 4th industrial revolution, the emergence of new features each day will probably elevate process complexity, leading to the compilation of already disseminated technologies to emerging resources, expanding practice's scope a lot further. This emphasizes the importance of both disseminating this integrated digital ecosystem beyond early adopters and understanding and being able to deal with the relationships in the interfaces that develop between them and the design process.

ACKNOWLEDGEMENTS

The authors would like to thank the participants and CAPES. This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001.

REFERENCES

ABNT, Associação Brasileira de Normas Técnicas 1995, *Elaboração de Projetos de Edificações: Atividades técnicas*, ABNT, Rio de Janeiro

AIA, American Institute of Architects 2007, *Integrated Project Delivery: A Guide*, AIA

Aish, R and Bredella, N 2017, 'The evolution of architectural computing: from Building Modelling to Design Computation', *arq: Architectural Research Quarterly*, 21(1), pp. 65-73

Bernstein, P 2012, 'Intetion to Artifact', in Marble, S (eds) 2012, *Digital Workflows in Architecture: Designing Design - Desgining Assembly - Designing Industry*, Birkhäuser, Basel, pp. 64-72

Deutsch, R 2017, *Convergence: The redesign of design*, John Wiley & Sons Ltd, Chichester

Eastman, C, Teicholz, P, Sacks, R and Liston, N 2011, *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors.*, John Wiley & Sons Ltd, Hoboken

Fabricio, MM 2002, *Projeto Simultâneo na Construção de Edifícios.*, Ph.D. Thesis, USP

Garber, R 2014, *BIM Design: Realising the Creative Potential of Building Information Modelling.*, John Wiley & Sons Ltd, Chichester

Gil, AC 2008, *Métodos e técnicas de pesquisa social.*, Atlas, São Paulo

Holzer, D. 2015 'Digital Convergence In The Design Studio', *Proceedings of CAADRIA 2015*, Daegu, pp. 469-478

Melhado, SB 1994, *Qualidade do Projeto na Construção de Edifícios: Aplicação ao caso das empresas de incorporação e construção.*, Ph.D. Thesis, USP

Mitchell, WJ and McCollough, M 1995, *Digital Design Media*, Van Nostrand Reinhold, New York

RIBA, Royal Institute of British Architects 2013, *Plan of Work*, RIBA

Scheurer, F 2012, 'Digital craftmanship: from thinking to modeling to building', in Marble, S (eds) 2012, *Digital Workflows in Architecture: Designing Design - Desgining Assembly - Designing Industry*, Birkhäuser, Basel, pp. 110-130

Succar, B 2009, 'Building Information Modelling framework: A research and delivery foundation for industry stakeholders', *Automation In Construction*, 18(3), pp. 357-375

Tzortzopoulos, P 1999, *Contribuições para o desenvolvimento de um modelo do processo de projeto de edificações em empresas construtoras incorporadoras de pequeno porte*, Master's Thesis, UFRGS

Zardo, P and Mussi, AQ 2018 'Mapping Design Processes Based on Intense Use of Digital Technologies', *Proceedings of SiGraDi 2018*, São Carlos, pp. 136-141

[1] https://vimeo.com/ukdug