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HAS TRUE BIM EVER HAPPENED?
ASSESSING BUILDING INFORMATION MODELING IN THE CONTEXT OF ARCHITECTURAL PRACTICE

Marcel Cadaval Pereira

Tese de Doutorado apresentada ao Programa de Pós-graduação em Engenharia de Produção, COPPE, da Universidade Federal do Rio de Janeiro, como parte dos requisitos necessários à obtenção do título de Doutor em Engenharia de Produção.

Orientadores: Francisco José de Castro Moura Duarte
Roberto dos Santos Bartholo Junior

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Examinada por:

Prof. Francisco José de Castro Moura Duarte, D.Sc.

Prof. Roberto dos Santos Bartholo Junior, PhD.

Prof. George Barnett Johnston, Ph.D.

Prof. Nelson Maculan Filho, D.Sc.

Prof. Fábio Borges de Oliveira, Dr.Ing.

Prof. Domício Proença Junior, D.Sc.

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Pereira, Marcel Cadaval

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AVALIANDO A PERFORMANCE DO BIM: BUILDING INFORMATION MODELING" NO CONTEXTO DA PRÁTICA ARQUITETÔNICA.

Marcel Cadaval Pereira

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Orientadores: Francisco José de Castro Moura Duarte
Roberto dos Santos Bartholo Junior

Building Information Modeling (BIM) é percebido como o santo graal da Engenharia de Arquitetura e Construção (AEC), que permite métodos inovadores de construção com o potencial de aumentar a eficiência do ciclo de entrega do projeto e da construção. Na prática, no entanto, seus benefícios permanecem relativamente pouco claros. Alegações de marketing não substanciadas e a falta de evidências empíricas adequadas resultaram em expectativas irrealistas sobre sua eficácia. Devido à natureza confidencial do setor, a avaliação abrangente do uso do BIM é escassa. "A indústria de AEC é um campo competitivo e as organizações muitas vezes relutam em divulgar sua expertise empresarial" (Eastman 2011, 396). Os estudos empíricos do BIM na literatura são interpretações de dados históricos - questionários realizados após a conclusão do projeto - ou testes de software realizados fora do ambiente do escritório, ignorando os conflitos e lutas do dia-a-dia. Com o objetivo de iniciar o preenchimento deste vazio, esta dissertação descreve um estudo etnográfico realizado dentro de uma prática de arquitetura. As transcrições e interpretações apresentadas neste trabalho estão focadas na eficácia do BIM, bem como no seu impacto cognitivo sobre o processo criativo, quando comparado aos métodos tradicionais.

Abstract of Thesis presented to COPPE/UFRJ as a partial fulfillment of the requirements for the degree of Doctor of Science (D.Sc.)

ASSESSING BIM PERFORMANCE:
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Marcel Cadaval Pereira

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Advisors: Francisco José de Castro Moura Duarte
Roberto dos Santos Bartholo Junior

Building Information Modeling (BIM) is perceived as the holy grail of the Architecture Engineering and Construction industry (AEC) that allows innovative construction methods with the potential to increase the efficiency of the delivery cycle of design and construction. In practice however, its benefits remain fairly unclear. Unsubstantiated marketing claims and the lack adequate empirical evidence have resulted in unrealistic expectations about its effectiveness. Due to the confidentiality nature of the industry, the comprehensive assessment of BIM usage is scarce. “The AEC industry is a competitive field and organizations are often reluctant to disclose their enterprise expertise” (Eastman 2011, 396). The BIM empirical studies in the literature are either interpretations of historical data - questionnaires performed after the project was concluded - or software testing performed outside the office’s environment, ignoring the day-to-day conflicts and struggles. Aiming to initiate filling this void, this dissertation describes an ethnographical study conducted inside an architecture practice. The transcriptions and interpretations presented in this work are focused on the effectiveness of BIM as well as its cognitive impact over the creative process when compared to traditional methods.

Contents

Introduction

“There is a feedback loop between technology and the people who use it. A changing consciousness calls for a changing technology, and a changing technology changes consciousness.” (Flusser 2011, pg 17)

I attended architecture school between 1997 and 2001, and at that time the so-called CAD systems were already wide-spread among professional practice. The majority of architecture offices in Rio de Janeiro had already implemented CAD to develop and generate the design documents, from conceptual design to construction drawings. The chosen software, with rare exceptions, was AutoCAD. A reduced staff could now produce the same amount of drawings in a much shorter period of time than had been the case five years prior. Despite the obvious progress achieved by the technology, architecture schools were still averse to it. Some of our professors argued that the digital environment would limit creativity and that shapes would be driven by the technical constraints of the tool rather than by designers’ intentions. Back then, the schools did not offer disciplines that taught the technology, nor were we allowed to use it in our design studios. While our school projects were being developed ‘by hand,’ our internships - common practice among college students in Brazil - were requiring proficiency in AutoCAD. The circumstances forced us to attend night or weekend AutoCAD private classes in order to meet the market requirements. The already unsynchronized dialogs between theory and practice of architecture were now even further apart[1]. After graduation I, like every architect, had to heavily rely on AutoCAD in order to perform my work, initially drafting for more experienced architects and later designing. In 2012, the office where I was employed was starting to implement BIM - a process of constructing an information-rich virtual simulation of a building that would replace the bi-dimensional CAD drawings. The digital model built by the BIM software could embed information about building materials, its cost and generate spreadsheets and drawings on demand. The software also allowed the development of automation that could potentially identify clashes among the design disciplines. A BIM software was installed in a few computers and just a few projects would be developed using it. We all had the impression that the technology might require some adjustments of design procedures. It was then that the old

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[1] Due to societal circumstances, the majority of practicing architects perform the work once performed by the draftsman, a supposedly extinguished profession of which architects are not trained for. This subject is discussed in depth by George Barnett Johnston at his book *Drafting Culture – A Social History of Architectural Graphic Standards.*

arguments from my professors popped-up again in my mind: Could a new technology, either CAD or BIM, really transform the design process? This question motivated my interests to become a PhD candidate at COPPE-UFRJ in 2014 and was the main driver of my research project. At COPPE, I was introduced to the work of Vilém Flusser, the source of the epigraph of this text. Flusser, one of the greatest thinkers of the twentieth century, dedicated a large part of his enormous production to studying and reflecting upon the relation among images, artifacts, visual communications, and -- most importantly for this study -- design. He considered that actions or work performed are defined, to some extent, by the tool used. He believed that the digital technologies, or "technical images," as he named them, could reshape critical consciousness and therefore the way we proceed.[2] These ideas had a direct relation with my personal motivation - could BIM really transform the design process? Flusser's thought, therefore, was deemed an apt critical filter for interpreting the object of my research project: the use of BIM in architectural practice.

The implementation of BIM has evolved since the beginning of this research, and so did the research questions:

What is the character of the architectural design process once BIM has been introduced to its fullest extent?

Has BIM changed the architectural design process?

In order to respond to these questions, I performed an extensive assessment of the literature up to mid-2018 as well as an ethnographic observation of the design work performed inside an architecture practice that had a BIM software fully implemented. The literature assessment clarified what BIM is and what it does. It also identifies contradictions within the same literature highlighting strong publication biases on the topic. The ethnographic observations validate the findings of the literature assessment as well as propose additional arguments that, although controversial, respond to the research questions above.

This thesis is therefore divided into three segments: The first segment initiates a discussion, based on Vilém Flusser's thought, about a potential shift of the critical

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[2] This is an over simplistic explanation of his philosophy. Relevant part of his work is discussed in depth at the first segment of this dissertation.

consciousness in the design process induced by a newer technology. The second segment presents the assessment of the literature: books, academic papers, and an ethnographic study of BIM usage in practice performed 8 years prior the present work. The third segment presents transcripts and interpretations of the field research, the ethnographic observations of the work performed inside an architectural practice. The findings of the literature assessment and the field research are synthesized in the last chapter. Three papers that derivate from this work are included as appendix.

SEGMENT ONE - Theoretical Filter for Analysis, The Sixth Rung

Vilém Flusser dedicated a large part of his production to reflect upon communication and design. The relation between design and communication may not be immediate, yet design is a social process (Bucciarelli 2002) that relies on communication in order to evolve. Ultimately, design and communication are interdependent particulars that can become the same thing through various occasions during the entire design process. In the book, *Into The Universe of Technical Images*, Flusser proposes a model that demonstrates the evolution of communication and its relation with societal advancement. His model identifies the invention of the phonetic alphabet as the apex of communication as well as societal evolution. One aspect that Flusser highlights about the phonetic alphabet is its ability to store external thinking, enabling the 'thinking' to be reflected upon; that is, interpreted. Another aspect heavily discussed by Flusser is the extent to which the tools can define/shape actions they perform. In the case of the phonetic alphabet, the linear way it displays external thinking is what enables linear-logic critical consciousness; much like the size of a hammer that can define the intensity of its stroke.

The following segment constructs an analogy between Flusser's model and the design process in architecture. It suggests that two-dimensional architectural drawing is an efficient repository of external thinking; much like the alphabet. Flusser reflects upon the replacement of the alphabet by technical images - or digital technologies - as a vehicle of communication. Based on his discussions, this segment reflects upon the replacement of hand drawings by newer digital technologies - CAD and BIM - as a vehicle of communication throughout the design process. This segment will discuss the role of different design tools, whether for writing or drawing, as a repository of external thinking and the extent of which these tools may alter the interpretation of the thinking that is stored. It will initiate discussion about a potential shift in critical consciousness - interpretation - within the design process, induced by a newer technology. It discusses the gains and losses of cognitive dimensions after the *digital shift*[3] and its impact on the architectural design process, based on Flusser's hypothesis that "human civilization has seen two fundamental turning points since its beginning. The first

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[3] The research project 89+, run by curators Simon Castets and Hans Ulrich Obrist, suggests the year 1989 as the benchmark for digital shift. Marked by several paradigm-shifting events (the collapse of the Berlin Wall and the introduction of the World Wide Web), it is believed that everyone born after 1989 has little or no experience with an "analog" world.

[…] may be defined as ‘the invention of linear writing’. The second […] may be called the ‘invention of technical images’ ”. (Flusser 2000: 7)

1. Philosophical background

Flusser argues that society evolves toward higher levels of abstraction. The *task of transmitting knowledge* is what determines the level of advancement or sophistication. At the beginning of the book *Into the Universe of Technical Images*, Flusser proposes a model for “knowledge transmission” that distinguishes five moments, or rungs, throughout human history where further levels of abstraction are reached. The five moments set out by Flusser can be summarized as follows:

On the first rung, primitive people were immersed in a concrete world; knowledge was transmitted by actions. Very little or no verbal communication was expected.

The second rung is the level of grasping and shaping, when the human beings that preceded us began to design and manufacture tools to improve their tasks. It was the beginning of the acknowledgement of the cause-effect rationale.

“Third rung: homo sapiens slipped into an imaginary, two-dimensional mediation zone between itself and its environment. This is the level of observation and imagining characterised by traditional pictures such as cave paintings.” (Flusser 2011: 7) These traditional images depicted habitats, routines; they were read and interpreted as the cycles of seasons, day and night, birth and death. Per Flusser, it marks the beginning of mythical-cyclical thought.

The fourth rung is the historical level: the invention and evolution of the phonetic alphabet and the concept of linear text that allowed for understanding and explanation, the beginning of consciousness. “A zone to which human beings henceforth owe most of their insights.” (Flusser 2011: 7)

The fifth rung has its beginning at the invention of photography and, later, electronic media: radio, TVs and computers. The second turning point in human civilization in Flusser’s hypothesis takes place at this level. Flusser, as well as many other philosophers – Ivan Illich, Ernst Cassirer, Susanne Langer, etc. – credit the phonetic alphabet as a major factor that is responsible for the way we think, act and behave. Its replacement by other media as a vehicle of culture would have crucial consequences on western culture and existence, consequences on historical consciousness (Flusser 2010).[4]

Every *new level of abstraction* reached is added to the previous ones. Potentially, levels are never disregarded, and there is a re-balance of strength among them and a tendency to prioritize the later one. The appearance of rungs overlaps, and their strengths are constantly rebalanced over time. Although it makes no sense to attempt to build a historical timeline for the emergence of each rung, it is helpful to understand how the transition between them might have happened, especially in order to understand the implications of the fourth rung, linear writing, on memory and consciousness.

2. The first turning point: third, fourth and fifth rungs

Although it is impossible to know the specific time in history when homo sapiens started to communicate with each other through organized speech rather than grunting sounds coming through the mouth, we can guess that it might have appeared sometime between the first and third rungs. The intention to record "communication" probably came not much later than the beginning of organized speech. Following Flusser's rationale, the first attempts to record communication were through symbols and later evolved into a pictorial-ideographical record. The evolution of *organized speech* and its first recorded attempts into formal language brought together a level of abstraction, a new level of consciousness and memory: the mythical consciousness, as named by philosophers. Ernst Cassirer was probably the first philosopher to consider that a deeper understanding of myths was needed.

Myths, sometimes crystallized in dogmas or vulgar superstition, were always excluded from the fields of any philosophical interest: *theories of knowledge* were only concerned with the appreciation of facts. Ernst Cassirer considered human beings to be "symbolic animals", using systems of signs and expressions as means of communication. The ability to define meanings was a human instinct that enabled mutual understanding. This background established the conditions for the origin of knowledge, the more "primitive" forms that underlie the more sophisticated cultural expressions. Cassirer's work

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[4] Per Flusser's view, history has as many interpretations as the number of interpreters (readers). Their conflicting views evoke further interpretations, and this loop of evolving ideas is historical consciousness.

sets up a discussion about the dialectical process through which religion and art developed from mythical thought, and theoretical science developed from natural language. Per Cassirer, “Myth never breaks out of the magic circle of its figurative ideas. It reaches religious and poetic heights […] But Language, born in that same magic circle, has the power to break its bounds; language takes us from the myth-making phase of human mentality to the phase of logical thought and the conception of facts” (Cassirer 2014: IX).

Flusser pays specific attention to the *record* of language and how it evolved into the reading and writing we have known since the mid-twelfth century. It took around 3000 years for the alphabet to evolve and spread across society. The evolution of levels of consciousness can be noticed throughout the transition from oral to written transmission. “From the seventh until well into the sixth century B.C., reading and writing were confined, in Greece, to very narrow circles. In the fifth century B.C., craftsmen began to acquire the art of carving or engraving letters of the alphabet. But writing was still not a part of recognized instructions […]. A full century before the stylus was imposed on pupils, they were able to learn the texts by heart” (Illich 1989: 23). Homeric epics and other books would be recited in their entirety by using mnemonic techniques such as rhythm and rhymes. The invention of the alphabet and its ability to record such works have induced a level of memory loss. A text, before memorized, was now attached to a clay plaque, parchment, and later, to a sheet of paper.

As well as the slow transition from oral to written transmission, writing and reading have also slowly evolved. At their appearance in the 7th century B.C., authors would write through the hands of others by dictation. Writing was a strenuous job (carving on a leather membrane or a clay plaque) until the invention of parchment and paper, and it was executed by a professional *scribe*. Around the 12th century, monastery libraries began to create catalog techniques in order to find manuscripts inside their archive. Texts were organized by theme, importance or date, and memory started to grow a new dimension. Texts were read out loud to an audience. Silent reading as we know it nowadays was a later stage in the history of reading, and yet it was the most important transformation, the detachment of the text from the page, discussed by Ivan Illich in the book *The Vineyard of the Text*. Although there was an evident loss in memory during the transition from oral to written transmission, the invention of the alphabet, silent reading, orthographic rules, and catalog techniques have given to humanity the ability to think critically, as discussed by Flusser. The phonetic alphabet, the fourth rung, gave us the ability to organize things in a specific order, going in one direction, not returning to the starting point. Only after the phonetic alphabet could cyclical thinking be overcome (Flusser 2010[5]: Langer 1984).

Besides the alphabetical order of organization and the idea of hierarchy, the alphabet has given us the ability to track whatever has been filed and consciously look into its internal co-relations in order to find logic and move towards the end of the line, the conclusion. As well as the organization of books in libraries, the subjects spread out over the pages of a printed newspaper and the location of typewriter keys, knobs on radios, vinyl players and film projectors, the analog world has been strongly driven by the alphabet. Flusser's hypothesis suggests that humanity is witnessing a second turning point, climbing a new step towards a higher level of abstraction, a new step yet unknown where critical thought might be reshaped.

"Flusser's original argument relies on its own historical period: the computers of that 'age' could only be manipulated by computer programmers. Interface platforms such as Windows or Mac OS would only be released years later, as well as software programs that would translate commands originally formulated in computing codes into commands adapted to ordinary users, with no knowledge of any programming languages. The idea of computer programming languages that would serve other languages could not be predicted yet" (Losso: FS 16). The general understanding during the initial ages of computing was: one would need to know computer programming in order to carry out a job/work/function in its most efficient way. However, it is important to acknowledge Flusser's efforts to understand the implications of computation during its embryonic phase: the black/green computer screens dependent on specific algorithmic codes in order to function, among other digital-technological advances. Yet, Flusser's hints about "the fabulous new way of life […] emerging around technical images" (Flusser 2011: 7) is one of his most interesting outcomes. What is taken by this work is the rationale with which his arguments are supported. In the digital "revolution" we are witnessing, the alphabet –

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[5] Per Flusser's view, before the invention of the alphabet the world could only be understood as it was presented, without further interpretations. For instance, the repetition of seasons and their cyclical relations with plantation, the cycles of day and night, and so on. The returning to a starting point was a dominant idea, and the "images" presented (seasons, day and night) would not allow for many interpretations as a written text, and therefore would not evoke conflicts that would cause the evolution of a consciousness. Flusser calls it mythical thought.

writing – is taking a peripheral role, and touch screens and virtual tools are the bigger players now.

Flusser's writings didn't consider the disappearance of writing, but its reshaping into an "algorithmic" format. Although the digital revolution didn't reshape writing into a computing code, the hypertexts, the filtering system of publishing, and the extensive reliance on iconographic language, among other examples, have given the virtual transmission of information a format that radically differs from twentieth-century writing and reading.

3. The sixth rung

Flusser's five rungs can be diagrammatically expressed as follows:

Actions – objects – traditional images – linear text – technical images (partially analog).

The traditional image is an observation of an object, and the technical image is a concept computed in an apparatus, per Flusser's definitions. The gesture of tapping with the fingertips on the keys of an apparatus, a topic extensively discussed by Vilém Flusser, is one of the concerns of this text. The problematics involving the technical images, especially at the beginning of computation, were determined by two considerations combined: (1) a technical image is an innovative way to express a concept. At the fourth rung, concepts were expressed by linear text, following a unidimensional rationale; (2) in order to express a concept through a technical image, one must learn a new alphabet, the computer codes, as well as be restricted to the possibilities of the apparatus, the black box paradigm.

Nearly 40 years after Flusser's writings, the need to learn a computer language in order to produce knowledge is not a reality. There was a shift in the black box paradigm, and the black/green computer screens populated by "new computer alphabets" were replaced by interfaces that tried to simulate the analog logic: the filing systems in virtual folders and their virtual trash, software for writing and drawing, etc. These simulations have become more and more sophisticated. The keyboard was almost completely replaced by mice, pens, tablets and, more recently, by our fingers. There is almost no need to use the alphabet, to write, in order to execute a function: we rely on our fingers' touch and iconographic information previously placed on the screen. It does not mean that the black box paradigm has ceased to exist; there are different levels of sophistication or intuitiveness within these different simulations of analog world. In the architectural environment, the subject of this study, the level of sophistication of simulations can affect enormously the social interactions alongside the design process. The black box is not a static barrier. There is a gradient characteristic within the barrier: layers of "intuitiveness" versus reliance on new knowledge as well as restrictions of the *apparatus*[6] itself. Vilém Flusser acknowledged that any technology is a potential transformative tool:

> "There is a complex feedback loop between the technology and the people who use it. A conscience in process of transformation calls for innovative technology, and an innovative technology transforms conscience." (Flusser 2010: 39)

One issue that is embedded in the statement above is the reliance on someone else's knowledge in order to produce knowledge. This has an evident effect on the design process. By design, I do not mean architectural or any other kind of artistic-creative processes only, but any kind of process that produces knowledge: art, science, and technology, as well as its management procedures. The gradient character within the *reliance on someone else's knowledge* relates to how easy or difficult is to deal with *the* new technology. Exploring this gradient is a matter of a detailed ethnographic research project, and therefore is not the focus of this work. This text explores the possible transformations of consciousness by the use of *the* new technology. The architectural process, the *object* of the following lines, is only a familiar domain that I can comfortably use to understand the subject. It is my hope that the rationale behind this work can be applied to other domains.

4. Drawing = writing? The traditional architectural image

The traditional handmade architectural drawing would not fall into any of Flusser's categories. It cannot be classified as *traditional* because it is not an *observation of an object*; nor is it a *technical image*, because it is not *computed in an apparatus*. The traditional architectural drawing is a handcrafted representation of a *concept.*[7] In this regard, the traditional drawing is equivalent to writing, as well as the text

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[6] Apparatus in this case refers to software and hardware and how they respond to each other.

[7] The word *Concept* may be misleading in this case. A concept in this case is anything that carries a displaced meaning. The answer to a question or a copy of an existing text can also be considered concepts.

that, in order to be interpreted, needs to be completed by the *next lines, paragraphs and pages*. The traditional architectural drawing needs to be completed by other media: texts, material samples, other drawings. The traditional architectural drawing is a rational/Cartesian translation of a concept, as it is the text. Its linearity is not as obvious and visual. One reason might be that the architectural *orthographic rules* vary from practice to practice, from builder to builder, and so on. As well as in texts, the analogies, metaphors, hyperboles and other figures of speech permeate all the media throughout the design process. The architectural design process seen through the lenses of Flusser's model can be described as follows:

- First rung (actions) – Client's briefing, site visits and any other essential social interaction.

- Second rung (grasping, objects) – Physical modeling, material and texture samples.

- Third rung (traditional images) – Traditional architectural image, as described above.[8]

- Fourth rung (writing) – Contracts, specifications and any other written means of communication.

- Fifth rung (technical images) – Images generated by apparatuses such as photo montages, airbrush renderings or digitally generated images.

As mentioned previously, due to societal changes and advancement in technologies, the complementary relationship among the rungs has changed throughout history. Actions (speech), objects (models, samples), texts (contracts), and drawings (traditional and/or technical) had different strengths in different *eras*, as well as different characters within each rung: clients, managers, designers, builders; design and communication tools, etc. For instance, in the fifteenth century at the construction of the Dome of Santa Maria Del Fiore Cathedral, Brunelleschi was the designer as well as the builder, and he himself directed the bricklayer.

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[8] As mentioned in previous paragraphs, the "traditional architectural image" is not classified as Flusser's traditional image. The Flusser model is used as a lens to understand the object, not as static categories of classification.

Brunelleschi designed through a physical model. He was known to keep his calculations and solutions a secret in order to keep the commission, forcing the builders to rely on him to accomplish the task. Five hundred years later, in the mid-twentieth century, the designer(s) would release a large number of drawings to the builder (a new player), without the risk of losing the commission: written contracts set out the rights and duties of each party involved.[9] Physical models and photo montages were extensively used as part of the process. Speech, texts, drawings and models were present, with different strengths, in both cases described above.

Moving forward 50 years in history, when the use of computation became detached from computing codes, from the mid-1990s onwards, the *new* computerized design process became highly efficient. Among the advantages of the newly created digital drawing technology, the two most prominent were: (1) to erase and redraw little bits of a drawing without the need to make up an entire sheet; (2) to copy, multiple times, a specific piece of design across the drawing. These advances had a strong impact on the architectural industry: a reduced number of staff were now able to produce a great number of drawings in a much shorter time. The digital two-dimensional architectural image, the CAD image, belongs to the fifth rung: it is a technical image.

Despite the black screens populated by colored lines and shapes, digital drawing technology, two-dimensional CAD, is still a simulation of a hand drawing. It translates one's thoughts into a two-dimensional geometric code of lines and shapes, line weights, shades and colors. Apart from the speed and reduced staff, the "vocabulary" and its "orthographic" rules remain unaltered, as well as the flow of information within the design process. The flow of the design process can be simplistically described as follows:

Actions and initial architectural images (traditional or technical) become a program.[10] *The program and actions (verbal communication) feed the design team; the design team produces further refined architectural images and texts; the refined images and texts undergo further actions; further actions adjust the program accordingly. The program and actions again feed the design team…* This

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[9] This is a topic itself. There is a book currently being written by Professor George Johnston, School of Architecture, Georgia Tech.

[10] Text that describes the client's requirements. It is the architect's starting point. It could be a single page or a multiple-volume document, depending on the complexity of the product desired. Generally, this document is constantly adjusted during the process.

continuous loop ends when a design is agreed upon or when the client is running out of time, whichever comes first. The number of loops until the project ends depends upon time, the complexity of the design, the ability of the design team and the ability of the management.

The so-called *digital shift* added new layers to this process. One new character, an instantaneous-simultaneous interaction, is changing the two-dimensional rationale behind the design process, as well as the information flow, oversimplified in the description above. The *objects* (text or drawings), as *works-in-progress*, can be edited by different actors simultaneously. The unidimensional linearity of the process has shifted to a network-like progression, the history of any design process has become harder to be traced, and a much wider range of interpretations is now available. The design objects (texts and drawings) have acquired new dimensions: the so-called *revision*, the *still moment* from an ongoing process, is not as *still* as before. This interactivity, added to the different levels of analog simulation, has clouded the lens that discerns the process.

Another feature of the simultaneous interaction is that one can easily access information previously placed in a source. The so-called virtual libraries embedded in the apparatus, a pre-determined group of materials, textures, details of joints and transitions, furniture, etc. Generally, these libraries are open to its users to add new items at any time, making it an enormous source of data. Dealing with this *big data* is becoming a matter that is more sophisticated than the creation of new data, the creation of new knowledge. The new consciousness has become a matter of finding, filtering and combining the relevant data from the existing source; it is not as much a matter of producing new knowledge. One can argue that the same rationale has its analogy in the twentieth-century analog libraries (the re-collection of pre-existing data and its further combination), yet two differences must be highlighted: (1) Not everything could be instantly and freely added to a twentieth-century source of data. There was a screening – a selective process previously made by one person or a group of people, the role of the editors, a subject discussed by Flusser. The discussions between authors and editors is controversial, and in many cases it has an authoritarian character, but the majority of knowledge produced was submitted to further discussions and would, anyway, evolve, even if it were still susceptible to rejection. The author-editor relationship does not apply only to books in libraries, but also to a standardization of details or material samples or anything that needed to be reviewed and accepted by a more senior authority. (2) The way the information was displayed during the analog era allowed for a much wider range of interpretations. The simple gesture of touching and reading a written text, a printed image or a tri-dimensional object, the acknowledgement of the real tri-dimensionality of the *things,* gives a sense of freedom/empowerment to interpret in an adverse or even skewed path.

The recently created design tool Building Information Modeling (BIM systems) adds an additional character to this problem, applied to the architectural environment. Cognitively distant from the two-dimensional representation, the BIM is not a simulation of a hand-drawing, nor is it a simulation of a construction site. It is a virtual construction site that exceeds the limitations of a two-dimensional representation. Any shape created in this virtual construction site can, potentially, be measured and built, considering the use of tri-dimensional printers and similar apparatuses. The mental process of understanding an object, breaking it down in plans, sections and elevations, is now placed within a computer algorithm to be sent straight to the *printer*. The representation of a helicoidal stair by a traditional two-dimensional method, for instance, would rely on descriptive geometry knowledge to produce accurate measurements. The gesture of drawing the lines to represent its steps, and the additional lines to represent the handrail, would ultimately force the designer or draftsman to acknowledge that the handrail should be joined to the step, even though this *joint* would be developed later on. In a BIM-like environment, an equivalent stair is pre-stored in a library. Joints, details, and textures are pre-set. Every parameter can be manipulated and new ones can be added, but the latter is rarely the case. In an environment that relies on pre-set data, the creation of new or bespoke features are even more distant from the design process.

The second turning point in human civilization hypothesized by Flusser may now be occurring. In the case of the design process, there is no longer a need to know descriptive geometry or two-dimensional representation in order to know how an object will be constructed or manufactured. Details, joints and finishes are either embedded within the “apparatus” or they are dimensions – impossible to be measured in a traditional architectural drawing – that will be sent to the printer, without further human thinking. Knowledge is being placed in a virtual model and, maybe, is freeing up mental room for new kinds of judgment, a reshaped critical thought.

The fifth rung proposed by Flusser, the Universe of Technical Images, had a tremendous impact on industry, economy and society. For instance the CAD software mentioned at the introduction of this dissertation. CAD was an efficient technology that sped up the process, as well as laid off a big chunk of the workforce. It was an efficient simulation of the analog world but did not reshape *historical consciousness*. We might be witnessing the beginning of a *Sixth Rung.* As a reference to Vilém Flusser's writings, it might be called the Universe of Virtual-Interactive Media: non-existent (virtual) tools manipulated by multiple characters, generating multiple possible results. As well as the *text* that became detached from the page around the twelfth century, tools are becoming detached from real objects and the complementary relationship among the five rungs has ceased to exist: actions, objects, texts, and images (traditional and technical) are now combined, merged in this virtual environment, and our consciousness is undergoing a transformation due to this *innovative technology.*

According to Flusser, "Two possibilities to face the world, one is through image and other is through linear writing" (Flusser 2013). We are facing a third possibility, a non-existing – or virtual - web of connections.

The *Flusserian* logic sets an interlacement between the fourth and fifth rungs: technical images and texts may restrain the interpretation of one another. At the sixth rung the nexus of intellectual technologies is much greater and its interlacement more complex. For instance, the *grasping* property of the second rung, not accounted as vehicle of consciousness in Flusser's rationale, seemed to be a highly important feature to carry consciousness at the sixth rung: tools acquired virtual functionalities detached from real objects. Its use is an interpretation itself as well as vehicle of consciousness, not necessarily the object produced by the tool. Interestingly the iconographic *vocabulary* placed at the computer screen and used by the virtual tools can be understood as a return to a pictorial writing, a neo-ideographic alphabet. In an architectural design process the design tool - BIM model - besides allowing indefinite kinds of uses, one of the big challenges is to grasp the X-*dimensionality* of its virtual existence. The *traditional* bi-dimensional representation is a simplification tool that eliminates the parallaxes of a tri-dimensional observation as well as provides its true dimensions. Any complementary information is carried by additional objects such as texts, schedules, physical and digital models, etc. The complementary relationships among these objects maintain their independence: they address each other but don't rely on each other's existence in order to operate. In the BIM model, a tri-dimensional virtual object, the complementary information is embedded within the system and depend on each other existence in order to fully operate. It is not possible yet to interpret all these layers of information by only observing these tri-dimensional virtual images bi-dimensionally projected onto a computer screen or bi-dimensionally printed on a piece of paper. Access to hidden information is necessary to enable interpretations that are equivalent to interpretations of texts, architectural drawings or even the interpretation of an interlaced system of texts and technical images. On the sixth rung, relevant information or data is not accessible right way, if accessible at all as this might compromise any further interpretation.

The consciousness of the design process, or its historical consciousness - an evolving loop of conflicting interpretations - is being replaced by a web of interdependent connections that not necessarily move forwards, not necessarily returns to a cyclical pattern. This virtual web of connections opens up possibilities that overcome the linearity of historical consciousness. An effect analogous to the overcoming of mythical thought by language. It might be the beginning of a new consciousness where any missing piece or turbulence at any one or more connections might take the system to undesired or unprecedented paths. We are experiencing an early stage of the sixth rung; therefore, any attempt at its description or acknowledgement of its effects on society is premature and ultimately inaccurate. Still, an admittedly incomplete definition must be advanced nonetheless in order to open a void for further criticism and keep the *flow* of historical consciousness, at least while it still remains in its actual shape:

The Sixth Rung is a level of interdependent information web: the invention and evolution of non-existent/virtual tools and simultaneous interactivity of its unities. A zone where linear thinking is replaced by multi possible dimensions.[11]

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[11] This statement fulfills the task to suggest a definition for the 6th Rung constructed throughout the text. It is not intended to be an optimistic hypothesis nor it is an unbiased reflective filter to assess BIM. The Sixth Rung refers to any digital tool created after the digital shift that functions as vehicle of communication. Affordances and weaknesses should be assessed for each case individually.

SEGMENT TWO - LITERATURE ASSESSMENT

The first segment of the dissertation introduced and inserted Flusser's Five Rungs Model into the context of AEC (Architecture, Engineering and Construction) industry. It identified that CAD systems played the role of Flusser's Fifth Rung within the design process. That is, an efficient simulation of the hand drawing that enabled severe reductions in the drafting workforce. However, the segment demonstrated that the use of CAD systems did not imply significant changes over design methods and process; therefore, over interpretation or critical consciousness, as suggested by Flusser. The segment also defined a Sixth Rung as the interdependent web of connections originated by the evolution of digital tools and the digital shift, and identified BIM as the Sixth Rung of the AEC industry. It highlights the **complementary relation** among the communication objects of a traditional design process – whether CAD or hand drawing - as opposed to the **interdependent relation** of the same objects when they are encapsulated within one tool – BIM. It stressed the fact that the objects - the two-dimensional drawings, the physical models, the texts of specifications, memorials and schedules of area and cost – used throughout the traditional design process should not rely on each other in order to operate. Under this panorama, the following two segments intend to assess the consequences/impacts of these design objects over the design process, when they are collapsed inside a single tool. The next segment is an assessment of BIM-related literature. The first part of the following text presents the assessment of books and academic papers. The second part is entirely dedicated to an assessment of an ethnographic observation of BIM usage in practice, possibly the only field research (ethnographic observation) on the topic completed prior to the field research presented in the third segment of this dissertation.

1. Clarifying BIM: four erroneous propositions

Building Information Modeling - BIM is perceived as the holy grail of the Architecture Engineering and Construction industry (AEC) that allows innovative construction methods with the potential to increase the efficiency of the delivery cycle of design and construction. In practice, however, these claims about BIM are still unsubstantiated and have resulted in unrealistic expectations about its functionalities and effectiveness. There is a divergence between claims/expectations and practice. Scientific literature has failed to situate BIM within the functionalities of digital design and demonstrate its realistic effectiveness. In this segment I identified four erroneous propositions that induced this overestimation of the applicability and effectiveness of BIM.

1.1 Introduction

Building Information Modeling (BIM) is a process of constructing an information-rich virtual simulation of a building, including its structure, infra-structure, components, and finishes - all the nuts and bolts. Due to its level of detail and concordance with physical reality, this tri-dimensional digital model can, theoretically, provide accurate and real-time data useful for cost control and scheduling as well as produce graphic outputs, drawings and details, as needed and in scales and formats appropriate to their use.[12] Although literature suggests that BIM complies with a wide range of contexts and modalities, our interpretation of the same sources does not agree with such optimistic point of view (Eastman 2011, Holden 2012, Kensek 2014). Our research reveals that the main purpose of Building Information Modeling is to enhance the management of design and construction processes.

BIM has been used as a generic definition for any digital technology that involves 3D visualization. This gives opportunity to terminological misuses, inducing the assumption that BIM platforms can comply with a variety of functions and uses that radically differ from its original management purpose. The distinct functions most often associated with BIM platforms are Digital Fabrication and Facility Management. The digital tools required to perform management of design and construction, digital fabrication, and facility management are highly differentiated. Scientific literature has only indicated efficiencies hypothetically achievable in the first of these functions while users are often motivated by positive assumptions supposedly applied to the other two.

The conflation of digital design functions turns the effectiveness of BIM into a magic word for clients and/or owners. But it also gives rise to reasonable doubts among designers. Despite the relative scarcity of empirical assessments demonstrating

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[12] One of the big features of BIM software is the ability to embed data in objects modeled inside the software. The nature of this data can vary: spatial dimensions or areas, amount of fixings (doors, windows) or material specification. This data can either be produced by the software or input into the software during the process. The software also allows automation to some extent, i.e. to highlight design errors. The data and automation grow larger and more complex as the project evolves.

BIM performance in practice,[13] there is a convergence between two topics in the literature that enables the measurement of the effectiveness of BIM: interoperability and maturity. These topics are associated with levels of software operability and user proficiency. The understanding of their progress over time illustrates the effectiveness of BIM platforms.

Based on the literature, this segment clarifies four erroneous propositions about BIM.

1.2 Brief Historical Overview of BIM

The idea of computer-aided architectural design began in the early days of computation. Since the early 1960's several attempts for conceptual frameworks and interfaces for 'computational' design have been made, but the first successful project was the Building Description System proposed in 1975 by Charles Eastman in his paper "The Use of Computers Instead of Drawings in Building Design" (Eastman 1975). Eastman highlighted the weaknesses of handmade architectural drawings and suggested how they could be overcome using computers. He proposed three-dimensional shapes created by computers, which could generate orthographic views by cutting "…sections through the shape to derive planes, sections, isometrics or perspectives from the same description of element" (Eastman 1975). This process could eliminate inconsistencies across a project caused by mistakes/errors in drawings made by hand. In addition, those drawings could be generated on demand, following consultants' or contractors' needs. Reports for cost estimation or any type of quantitative analysis could be easily generated as per Eastman 1975. These ideas have influenced many research projects throughout the world, but Eastman's digital lab established at Georgia Tech is still today the benchmark for design and construction using digital technologies.

The so-called Computer Aided Design (CAD) only became popular from the 1990s onwards using software developed to mimic two-dimensional hand-drawings. The drawings were produced following the same rationale as descriptive geometry used by traditional hand-drawing: plans, sections and facades drawn on digital

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[13] The majority of empirical data presented through the academic literature is based upon historical data. That is, surveys or interviews performed after a process is completed. Due to the confidential and liability nature of the AEC industry, ethnographic observations of BIM usage by design practices while the project is going on have not been systematically performed yet.

boards, later by mouse and visible on computer screens. This *new* computerized design process was highly efficient when compared to traditional methods. Among the advantages of the newly created digital drawing technology, the three most prominent were the ability to: (1) erase and redraw little bits of a drawing without having to redraw an entire board; (2) copy a specific piece of design multiple times across the drawing; (3) almost instantly print out as many copies of a drawing as needed. These advances had a strong impact on the architecture industry, as a reduced number of staff were now able to produce a greater number of drawings in a much shorter time.

In his 1975 paper, Eastman had hypothesized that additional capabilities would be realizable by the generation of two dimensional drawings from tri-dimensional models. These included the reduction of drawing errors and inconsistencies as well as the ability to make accurate quantity take-offs for cost control and estimating purposes (Eastman 1975). By the end of the 1990s, several platforms such as AutoCAD, Micro Station and Micro GDS were already testing how to embed data such as material specifications and cost factors into the drawing; but the input, revision, and retrieval of that information could take so much effort that older methods of writing the data in separate files were still more efficient. The concept of file sharing, i.e. a single file being used simultaneously by members of multi-disciplinary design teams, was a later development not originally anticipated in Eastman's 1975 paper.

By the early 2000s, the three-dimensional aspect of BIM was consistently incorporated into available software. In addition to the possibility of generating two-dimensional drawings from a three-dimensional model, attempts at automation were already being implemented. The 3D models could potentially identify building regulations and information clashes among the design disciplines (consultants) while information about materials, finishes and equipment could be embedded into the 3D models allowing some level of quantity take-offs as well as data retrieval. Taken together, these capabilities showed enormous promise for improving the management and efficiency of the design process as Eastman had first suggested.

1.3 The Four Erroneous Propositions

In addition to the primary focus of Eastman's 1975 paper, BIM is frequently adopted by key authors and designers (Eastman 2011, Holden 2012, Kensek

2014) as a generic term that refers to two other functions of the design and construction cycle: digital fabrication and facility management. The failure to make these distinctions clear conflates claims and expectations. The capabilities demonstrable in one of these domains of digital design (Digital Fabrication, Facility Management, and Design Management) are not, per se, achievable in all three.

1.4 Erroneous Proposition One: *Digital Fabrication is a Function of BIM platforms.*

It is difficult to define whether digital fabrication unfolded from Chuck Eastman's original proposal, or if it was researched and achieved elsewhere and later incorporated by Eastman's digital lab at Georgia Tech. Nevertheless, Digital Fabrication is an independent process in which a building part is designed through and fabricated from digital media, a tri-dimensional model. However, the software used for Digital Fabrication is not ideal for the BIM process of data input and retrieval. The 'digital fabrication model' needs to be imported to a BIM software in order to provide ideal design management. There are already initial attempts to incorporate Digital Fabrication features inside BIM software but at present they have not yet succeeded.

Although Eastman did not acknowledge the possibility of Digital Fabrication in his 1975 paper, it was the first function of Digital Design that was widely reported by media. The Guggenheim Museum Bilbao designed by Frank Gehry (1992-97) was the first project developed through so-called Digital Fabrication widely reported (Chang 2015). The gestural shapes that defined the museum's "envelope" were impossible to represent and construct using Euclidian Geometry, i.e. traditional two-dimensional drawings.

Gehry's team had already struggled in a previous experience when he was commissioned to design the Pavilion for the Barcelona Olympics in 1992. A contractor had failed many times to build a mock-up of the "fish shaped building" using two-dimensional drawings when they came across Catia software used to develop the French Mirage aircraft. The software was able to calculate and measure organic/irregular shapes through a 3D model that represented the design intent. (Chang 2015)

After the experience gained through the Barcelona Pavilion and the Guggenheim Museum design processes, Frank Gehry established Gehry Technologies,[14] the first BIM consulting firm in history. Inspired by Catia software, Gehry Technologies also developed its own software, designed specifically to handle gestural shapes. The software is not extensively used by the AEC industry, however, due to its extremely high cost and being specifically tailored to the demands of gestural shapes (Chang 2015).

During the twenty years that passed following construction of the Guggenheim Museum in Bilbao, many software packages were developed specifically for the AEC industry to handle BIM processes and 3D modeling. Around the year 2000, BIM platforms became accessible to architects, engineers and contractors. Practices such as Zaha Hadid, Morphosis, UNStudio, Foster and Partners, and OMA, to name a few, began using the software tools frequently in order to develop and construct buildings with gestural shapes. These buildings and their strong exposition in the media contributed to Digital Fabrication remaining the most popular function of the Digital Design.

Digital Fabrication is an independent process in which a building part is designed through and fabricated from digital media. Digital fabrication software does not include features that support BIM processes. Yet many reference books about BIM include chapters solely about Digital Fabrication. Chapter 7 of Chuck Eastman's BIM handbook (Eastman 2011) is dedicated specifically to Fabricators. It discusses automated manufacturing, prefabrication and assembly. The only aspect of fabrication specifically linked to project coordination is the benefit of paperless processes when correlated to the cost of the detailing as compared with traditional processes. The chapter also underlines the ability to produce 3D visualizations as a powerful advertisement tool, a feature to assist in obtaining work; however, 3D visualization is not a feature associated with BIM or DigiFab only. Any technology that involves 3D modeling can benefit from it.

3D visualization does not necessarily need to be digital. A digital 3D model is more mobile but not radically different than buildings drawn in the perspective space invented in the Renaissance (Yaneva & Latour 2008). The cost and time consumed

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[14] Gehry Technologies was lead by Dennis Shelden, one of Frank Gehry employees (Chang 2015). Shelden described the design process of the Guggenheim museum at his PHD dissertation defended in 2002 at MIT. In 2016 Dennis Shelden was hired as the new director of the Digital Building Lab at Georgia Tech on the advent of Professor Eastman retirement.

to produce any graphic representation able to illustrate finishes and details of a building in all its minuteness is very high, regardless of whether it is digital or handmade. The digital version can provide a dynamic or "fly-through" visualization entailing additional cost and production time tied to technical requirements. Nevertheless, both versions serve illustrative purposes solely.

Chapter 7 of the BIM Handbook (Eastman 2011) becomes even more confusing with the inclusion of a table called "BIM software for subcontractors and fabricators." This table groups software of different functionalities under the same umbrella (so-called BIM software), even though the content makes clear distinctions between software for fabrication and software for coordination.

Chapter 2 of the book Building Information Modeling (Kensek 2014) discusses the functionalities of digital design, considering Digital Fabrication and Facility Management as distinct competences of BIM. BIM is a generalization for a variety of software used for Digital Fabrication and Facility Management by stakeholders.

Chapter 16 of the book BIM: in current and future practice (Kensek; Noble 2014) mentions BIM in the title; however, it does not discuss the coordination aspects of digital design.[15] The chapter discusses software and modeling constraints imposed by material properties and the standard dimensions available in the market. It does mention Revit, a BIM software, referring to it as a holistic modeler while dismissing the fact that Revit does not support fabrication. The "holistic digital model" will ultimately need to be exported from Revit and imported into an appropriate software for Computer Aided Manufacturing (CAM) in order to be fabricated. The interoperability between the software is ignored.

Part of the scientific literature is failing to distinguish functionalities within the realm of digital design (Eastman 2011, Holden 2012, Kensek 2014). It also assumes that digital processes are changing the modes of existence in general: communicating, commuting, shopping, housing, living (Jeong 2009, Steel 2010, Eastman 2011, Holden 2012, Case 2014, Ghaffarianhoseini 2016). In the Architecture Engineering and Construction industry, some of these misplaced arguments are motivating clients and owners to require BIM as a mandatory platform. One proponent extols BIM as "the key technology leveraging change and innovation in the construction

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[15] Chapter authored by Christopher Beorkrem, UNC Charlotte School of Architecture.

industry that is offering the opportunity to totally reinvent contemporary construction design and delivery practice for future development.” (Ghaffarianhoseini 2016).

There are many books[16] that discuss how Digital Design is reshaping the AEC industry, in terms of both the practice of architecture and the digital generation of architectural form. This debate is largely based upon the following two premises: 1) the enhanced capability to investigate materials and construction methods and logistics enabled by the Digital Fabrication processes in the realization of complex gestural building forms and assemblies; and 2) the new potentials of mass customization as compared to mass production.[17]

These two arguments do not address the coordination function of digital design which is its dominant role of the industry rather they over emphasize the importance of BIM or digi-fab. According to Kedan (2010) the majority of architectural practices consistently exploring digital fabrication are located either in US or UK, and “much of the manufacturing they rely on as well as the majority of their clients are located in expanding economies of Asia” (Kedan 2010). Nevertheless, digi-fab projects are typically developed within very exclusive contexts and receive enormous exposure in the media despite representing only a small portion of the AEC industry.

1.5 Erroneous Proposition Two: *Facility Management Is a Function of BIM Platforms*.

Facility management is a practice that coordinates maintenance and operational strategies of a building as well as the management of human resources and information technology. Although it is reasonable to assume that buildings of any kind have required some level of maintenance and operational management throughout the history of architecture, there is nonetheless an extensive debate in contemporary literature about the origins of Facility Management (FM) as a discipline (Nor 2014).

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[16] such as Building (in) the Future (Deamer 2010); Emerging Models of Architectural Practice USA (Kedan 2010); Integration Innovation in Architecture (Aksamija 2016); Digital Workflow in Architecture (Marble 2012) to name a few.

[17] This concept is discussed in depth by Mario Carpo in his book *The Alphabet and the Algorithm*.

History provides us with many examples of FM: healthcare facilities from the 10th century already required high-level operational and maintenance strategies; so did the ‘Grand Hotel’ from the late nineteenth century with its nearly one thousand sleeping rooms, dining rooms and ballrooms. The 24-hour-service luxury hotels from the mid-20th century required constant maintenance of their enormous amounts of machinery, in addition to the complexity of their operational logistics (Mindlin 1962). Operational and maintenance logistics were coordinated through spreadsheets and schedules produced with pen and paper. In the late twentieth century handmade spreadsheets were replaced by software specifically designed for facility management. As buildings or facilities become more complex, the management of their functions needs to be more strategic and tactical (Nor 2014).

By their very nature, these buildings or facilities require regular renovations and expansions. Architects responsible for the design were also increasingly responsible for providing the necessary information to enable this Facility Management through an accurate survey of the building as it was actually constructed – the “as-built” drawings.

Literature regularly describes Facility Management as a sub-topic of digital design and suggests that it is a feature of BIM software (Eastman 2011, Holden 2012, Kensek 2014, Aksamija 2016). Eastman’s *BIM Handbook* argues that BIM’s contribution to facility managers is to optimize management and maintenance providing all relevant as-built data and equipment information. The book *Integrating Innovation in Architecture* (Aksamija 2016) claims that BIM encompasses the entire life cycle of a building, including Facility Management after completion. It suggests that BIM offers a new method for management of buildings that could ultimately skip the phase of as-built data collection. So BIM is seen as a provider of an unified database of all building components, allowing all types of information (including manuals and specifications) to be stored and to become retrievable whenever necessary. In short, the digital tool would be able to track all building uses, equipment location and perform the necessary calculations to support FM. The book *Building Information Modeling (*Kensek 2014) argues that strategic planning, management and operations are among the applications of BIM. Unlike the other authors, however, Kensek identifies the additional cost implied by the application of BIM to the task of facility management. Her book suggests that architects, owners and contractors should discuss their responsibilities regarding inputing data and updating the BIM model, clarifying this responsibility in the contracts or even considering hiring a third party for this role.

Under this perspective BIM would no longer be a mere Building Information Model. Once the design is concluded, the entire database and automations of this final version should contain enough information to become a Facility Management model. The BIM model produced by the designer will always need to be adjusted in order to accommodate the construction methods of the contractor hired. Different clients or owners will require different kinds of data for Facility Management, and so adjustments will often be necessary. But some of this data may not be relevant for the designer and/or constructor.

Information needed for Facility Management will be spread across at least two models: the design model and the construction model However, neither of these are yet the so called as-built. The construction of an 'as built/FM model' requires a survey of the building after its construction is completed. This exercise is an additional (and high) cost.

Another assumption among clients and owners is that the BIM/Facility Management model could replace Facility Management (FM) software due to the amount of data it contains and the automation it presumably allows. However, the relevant data must be retrieved from the BIM model, i.e. exported, and then imported into the Facility Management software. This export / import process and the interoperability among these platforms is an important topic in the BIM technical literature that is discussed later in this paper.

Nevertheless, in the literature there are frequent claims (Eastman 2011) that the final BIM model will respond to the owner's needs if the project is developed in a highly integrated way, with all the stakeholders – owners, designers, contractors and sub-contractors - involved from the early stages of the process. Such claims are embedded in two fallacies: (1) that the model is continuously updated during construction to reflect changes in the field; and (2) that highly collaborative projects are the majority of the AEC industry. These ideas do not match the facts, since in the most cases the constructor is hired through a bidding process only after the design is concluded. Designers convey the BIM model to the hired constructor and subcontractors. Not surprisingly, this model can undergo significant changes, especially in consideration of the additional intellectual ownership issues and contractual liabilities. Usually, the information necessary for FM is further apart since some of the stakeholders who own the information have probably never met, and the responsibility of collecting and organizing the FM data becomes cloudy. This can mean not only additional costs to contracts but often a new contractual agreement altogether. Rather than being a seamless extension of BIM functionality, Facility Management turns out to be an independent process that, potentially, uses the data embedded in a specially-commissioned as-built BIM model.

1.6 Erroneous Proposition Three: *Interoperability Is a Solvable Technical Issue*

The biggest asset of BIM software is the ability to aggregate different kinds of data in a single source. This ability implies an interaction with other software in order to read and process this data. The precision and smoothness of this process – the import and export of data from software to software - is imperative for the accomplishment of the so-called BIM. These file exchange procedures, known generally as interoperability, occur on many levels of the design process: exporting geometrical data to a specific analysis software - environmental, structural or any other design related discipline; exchanging numerical or textual data required for costing and/or scheduling; exchanging geometrical information between companies that use different BIM platforms. These are just a few examples.

The majority of books and handbooks on BIM have chapters entirely dedicated to interoperability (Eastman 2011, Kensek 2014). The topic is also a dominant focus of scientific papers. The books have a more theoretical and optimistic approach than the scientific papers, while the papers typically demonstrate the performance of interoperability based on empirical data. In order to enable and facilitate interoperability, many file extensions have been created and agreed among software providers. These exchangeable files are presented in books and tested in scientific papers, but neither describes in depth the discussions leading to their creation. The discussions are mainly concerned with intellectual property rights of each proprietary software producer. The first exchangeable format open to the public domain was only created when NASA found that they were expending significant amounts of money paying for translators among all their CAD developers. A NASA representative decided to bring all the CAD software companies together and demanded a solution (Eastman 2011, pp.105).

The amount of information that a digital file can contain is so great that the legal discussion between companies is mainly about how much of the original information will be accessible in the exchangeable file - for instance, exchangeable files for text that do not keep the original formatting of fonts, paragraph layouts etc. Only the textual content, without any formatting, may be accessible; or in multi-layer images only editable in the software of origin that become a still image in any other viewer. The limitations on accessible information in exchangeable files implies the need for redundant work: the need of re-editing or re-inputting lost data once the file arrives in its final destination. *The BIM Handbook* (Eastman 2011) argues that architects should understand the technicalities of these “public” or “open” files in order to enhance the re-entering or re-editing data. Kensek 2014, on the contrary, attributes this responsibility entirely to software producers. She writes:

> There are no serious incentives for a software company to allow exporting of its models to other external software programs other than pressure exerted from the user community to make this available. Although there is certainly a need to protect a company’s intellectual property rights, a balance needs to be achieved so that vital project information can be shared freely between different software programs. An altruistic notion to be sure, but only this will provide an open framework to drive innovation in both the development of BIM tools and techniques, which is a necessity to advance the building industry to the next stage of development of BIM applications. (Kensek 2014, 87).

Another implication raised by these legal discussions is the accessibility of files in the future:

> “Will the original applications used to create the BIM be available 1, 5, 10, even 20 years in the future? Will the file format be accessible to whatever the current version may be at the time considering that current tools are rarely backwards compatible more than a couple of versions?
>
> …the issue of obsolescence is not a new problem in design firms …, the absence of a media reader like a 5″ or 3.5″ “floppy disk” might make “archived” files inaccessible. BIM files have the same problems

> compounded – there is a good likelihood that there are many files that describe the project that also have to be accessed" (Kensek, 2014, 89-90).

As mentioned previously, scientific papers demonstrate the performance of interoperability based on empirical data. That is the efficacy of these file extensions. The short assessment of scientific literature shown below indicates the progress of interoperability and its exchangeable format extensions over time.

Jeong et al. (2009) - conducted a laboratory-like experiment that tested the process of exporting files from four different BIM software and importing them into two different "precast concrete BIM tools" - which are external software plugins designed specifically to calculate precast concrete objects. The same architectural object - a building facade - was modeled four times, each time by a different software.[18] These digital models were exported in three different formats[19] by each BIM software and imported to two different external plugins[20] as well as back into a BIM software, different than the original modeler. Although the paper is not based in realistic/ practical case studies, it concludes that "much work is still needed to achieve fully effective interoperability … tests showed clearly the need for a mutually agreed upon standard that defines how precast architectural facades should be modeled …."

Steel et al. (2010) highlighted the most common problems encountered with the interoperability of files across the design team. Models exported to another BIM platform used by a design partner were appearing out of position or missing parameters or basic dimensions. The complexity of the model in advanced stages of the design phase also generated large files and often created systems restrictions based in memory consumption, for example models not loading, failing to render, and/or not generating correct 2D drawings. The methodology of this paper is not explicitly described, but it is assumable that the paper is based on academic experiments (3D modeling) developed for the purpose of the paper only.

Oduyemi et al. (2017) identified and ranked the most common barriers of BIM specifically for sustainable building design. This study performed and analyzed a

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[18] The softwares were: Revit Building v9.1, ArchiCAD v10.0, Digital Project v1 R3 and Bentley Architecture v8.

[19] The file formats are IFC, DWG and SAT.

[20] The plugins were Tekla Structures v13 and Structureworks Precast

survey-questionnaire completed by 69 companies. The results of the analysis revealed that the lack of interoperability remained among the greatest technological challenges of BIM platforms.

According to Arayici et al (2018), interoperability in BIM remains low. Despite the available standards, IFC and IDM, there is still no clear guidance on how such standards can be effectively used for performance-based design.[21] The paper identified that due to poor interoperability, the software for Building Performance Simulation are currently being used only to check energy codes after the design is mostly completed. The study is a theoretical attempt to develop an interoperability specification method based on design methodology proposed by Design4Energy (D4E) research project. The D4E is a framework, also theoretical, that aims to predict the future energy demand of buildings.

Jin et al (2018) aims to understand the practitioner’s perceptions of BIM implementation in China. 94 BIM professionals were randomly selected and assessed by a questionnaire method. The research concluded that the interoperability among the BIM tools used by different project teams remains a technical issue for further investigation.

The excerpts above suggest that BIM interoperability has not progressed as expected. Despite research efforts aiming to create – or agree on - an ideal open source file format, and considering divergent opinions among these authors, interoperability seems to be as much a legal as it is a technical issue. The commercial aspect of intellectual property of software is a barrier difficult to overcome. The ownership of software by its creators, the ownership of products created by the software and the licensing system that imposes a dependence on particular digital tools is a matter that goes beyond the technical capabilities of users and software developers. This legally imposed lack of interoperability can be a high cost that ultimately falls into clients’, owners’ and designers’ laps.

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[21] IFC is an open source file extension and IDM, which stands for Information Delivery Manual, is an ISO attempt for standardization of information sharing/ software settings.

1.7 Erroneous Proposition Four: *High Maturity Ensures BIM Efficiency*

The transition from two-dimensional CAD to BIM software and the afore-noted struggles with interoperability demonstrate a “weakest link” phenomenon. If one single member of a design team cannot adequately comport with the dictates of the common platform, then the full collaborative potential of BIM is not realizable. Different levels of software proficiency across the design team affect BIM performance. In the scientific literature, much has been discussed about the level of BIM implementation focused on measuring the ability to operate within BIM platforms and exchange information among the stakeholders (Succar et al 2012, Chen 2014, Copping et al 2016). According to Copping et al. (2016) BIM levels are measured by theoretical assessment models that are usually based on a 5-level scale (1-5) suggested by Succar et al. (2012). BIM maturity, or the BIM level, is increasingly becoming a qualifying condition for public bidding and a requirement imposed by clients when selecting among competing architectural firms.

According to Chen (2014) et al., BIM maturity is measured by four dimensions; 1) hardware infrastructure, 2) software infrastructure, 3) human proficiency on the platform (software and hardware) and 4) management and delivery. These metrics assume the latest BIM software installed on powerful computers operated by trained personnel. The efficacy of information management-delivery is an evaluation of team efficiency using the combination of the other three dimensions described. Each of these dimensions is scored within different areas such as: workflow, senior leadership, training level, quality control, standardization, etc.

As reported by Copping et al (2016) there are 16 assessment models available to date. The scoring system and measured areas vary for each model while the dimensions measured -- computer power, appropriate software, software proficiency and personal efficiency -- are the same for all the models. The majority of the models involve self-appraisals based on a questionnaire, usually in “multiple-choice” format. According to Copping et al (2016) the most reliable assessment model was developed by Building Research Establishment (BRE),[22] a British private institution that provides the BRE-BIM-level 2-certification (2015), among other certifications for the AEC industry. In the British BRE certification system a

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[22] Building Research Establishment (BRE) is a center of building science in the United Kingdom, a former UK government national laboratory that was privatised in 1997. BRE provides research, advice, training, testing, certification and standards for both public and private sector organisations in the UK and abroad.

third-party is required to complete the assessment, which incurs a fee while the other models are self-assessments freely available to the wider industry. Some practices claim that the models only focus in one area and not on the entire project. In 2014, for instance, Arup developed its own assessment model that supposedly accounts for a wider number of variables.

Most theoretical assessment models measure BIM maturity based on the 5-level-scale (1 to 5) suggested by Succar et al (2012). The maturity scale suggested by National Building Specifications (NBS), the British organization that sets standards for the AEC industry in UK, is the model used by BRE for its BIM-levels Certification. The NBS maturity levels run from 0 to 3, differently from the 5 levels suggested by Succar et al (2012). The scores earned on the assessment determine the company's BIM level. However, the BRE appraisal questionnaire is confidential. In theory, even the assessed practice does not have access to it. An appraiser is sent to the design practice being assessed in order to observe, ask questions, take notes and fill out the BRE questionnaire. Throughout the appraisal process, the BRE appraiser may make recommendations in order to improve the company's scores in a later reassessment. Although the BRE procedure is a practical application of a maturity model, it remains a conundrum due to its questionable claims of confidentiality.

Additionally, BIM levels in theory measure the proficiency of the design and construction teams in terms of the integration and interoperability among all the different stakeholders and design disciplines operating within the BIM platform. Accordingly, any BIM certification granted to a single company can be misleading because BIM maturity relates to the BIM level of the team as a whole. It cannot guarantee that any processes performed by a single participating company will reach the BIM level of the certification granted. Both models tackle BIM-software proficiency among members of a team. They do not consider, however, "day to day" complications due to software imperfections or the obstacles commonly encountered when variable levels of software proficiency are present within the same team. Variations are also possible in terms of the different ways software may be implemented by different users or teams with regard to established BIM standards. Considering that in the AEC industry the members of a design team may have different kinds of expertise by nature, it is very likely that the BIM software will be used within a spectrum of different approaches, at least at the initial stages of the design or until design standards are agreed. Both models -

NBS and BRE - are conceptual recommendations, according to Chen et al (2014), most studies were limited to the theoretical proposal, and there is limited empirical research to test the reliability and validity of the models and frameworks.

According to Copping et al (2016), most studies have focused on introducing and promoting new models, rather than implementing them in the AEC industry. In addition, there is still a shortage of literature which examines *assessment models* in practice. Interestingly the maturing assessment model proposed by Copping et al (2016) was actually developed by Arup in order to measure Arup's own BIM maturity.[23]

Smits et al. (2016) suggests that the impact of BIM maturity on project performance is limited and cautions against over-optimistic appraisals of BIM. Smits et al (2016) presents the results of a large-scale survey research performed among 890 Dutch AECO professionals. The survey tried to understand and measure the relation among time, cost and quality performance. The results showed that the effect of BIM maturity on cost and time performance was surprisingly low.

According to Arayici et al (2018), for projects focused on environmental performance and sustainable design, the full potential of BIM has not yet been achieved because of a lack of integration that prevents collaborative relationships amongst team members throughout the project lifecycle. This is due to lack of clear guidance or the low level of BIM utilization. BIM's use in practice has mainly been at Level 1 and has only rarely attained Level 2.[24]

Despite the lack of empirical evaluations of BIM in practical application, some countries have systematically mandated the use of BIM for centrally procured public projects. In 2011 the UK Government Construction Strategy demanded BIM level 1 as requirement for participation on public bids (Government Construction Strategy 2011-2015). The UK Construction strategy 2016-20 requires BIM level 2 (Government Construction Strategy 2016-2020). Note that the maturity

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[23] Arup is a British Design and engineering company founded in 1946, holding branches in 35 countries to this date.

[24] Level 1 BIM - Comprises a mixture of 3D CAD for concept work, and 2D for drafting of statutory approval documentation and Production Information. Electronic sharing of data is carried out from a common data environment (CDE), often managed by the contractor. Models are not shared between project team members.
Level 2 BIM - All parties use their own 3D CAD models, but not necessarily working on a single, shared model. The collaboration comes in the form of how the information is exchanged between different parties. Design information is shared through a common file format, which enables any organization to be able to combine that data with their own in order to make a federated BIM model, and to carry out interrogative checks on it.

assessment and certification accepted by UK government is only performed and provided by one private company, the Building Research Establishment (BRE) mentioned earlier in this paper.

To date, UK, Scandinavia and Australia are the only places where BIM is mandatory in public bids. However, it is fair to say that in Scandinavia and Australia the levels of BIM adoption are varied and disjointed. There is no consistent approach to the measurement or level of maturity (López 2016). The other countries that claim to use BIM still have published guideline recommendations and provisions for full implementation in the future. Spain, for example, first published in 2015 its vision for the adoption of BIM level 2 by 2018. The *Recommendation Guide* published in 2016 and updated in 2017, however, does not mention a specific BIM level and remains the latest official document released by Spain planning authorities. Then, in 2017, adding further confusion, Spanish planning authorities announced that BIM level 1 would be mandatory starting in 2018. The same rationale to "push forward" applies as well in other developed countries such as France, Belgium, and Germany.

Turk (2016) questioned the slow dissemination of BIM platforms. According to his paper, if BIM is as good as advertised, why should its use in private investments be mandated by law? There was no government action to force businesses to start using the web, mobile phones, and management information systems. Some businesses did and succeeded; others did not, failed and lost in a competitive market. Industry is rational; it uses what is useful.

Interestingly numerous papers use social theories of technology diffusion in order to explain the lag-time in full BIM implementation. A paper written by two professors of the Northumbria University in the UK aims to measure the current level of implementation of 4D BIM in UK. 4D BIM implies in adding scheduling data to components of the model enabling the generation of program/ timescale information. Linking in cost data in order to support cost planning and generate estimates is known as 5D BIM, whilst the inclusion of information to support facilities management and operation is called 6D BIM. 4D, 5D and 6D are the newest trend in the BIM theoretical realm. Gladson et al (2017) used the *Innovation diffusion theory* proposed by Everett Rogers to analyze a questionnaire-survey that was completed by 97 design practices. As an outcome, the work suggests that future research should include qualitative investigations and consequences of 4D

BIM adoption. These suggestions reveal that the 4D BIM is still in an embryonic phase of implementation in UK.[25]

Rogers' theory is frequently referenced by papers about BIM as an explanation for the slow progress of BIM diffusion; however, its use is questionable considering that 4D BIM is a digital, not an analog, technology. Rogers' theory attempts to explain the rate at which innovation spreads; however, at the time *Innovation Diffusion Theory* was first published in 1962, the speed of technological innovation was much slower than today, especially when compared with the frequency of software releases. Besides, at that time innovations would take much longer to spread across society due to distribution logistics and cost. Today, a new software, or its new version, can reach a large market of users within hours, in some cases with no cost. Society is facing a new condition where digital innovations are happening at such speed that it does not allow enough time for a new technology to be learned, used and adjusted according practice. The intercession of the internet has radically accelerated the rate of technological diffusion.

The measurement of BIM implementation and the assessment of BIM maturity levels are still highly theoretical at this juncture. They lack adequate empirical evidence of BIM applications and remain controversial in regard to BIM certification and its adoption as a mandatory platform. Generic claims about BIM innovativeness and unverified promises of lower costs and shorter construction time are among possible motivations for planning authorities to dictate BIM adoption for public sector projects. Efforts to assess BIM proficiency, as well as the rhetoric of technological innovation, are among the arguments inducing clients and owners to demand specific levels of BIM for their projects despite questions about the validity of the assessments and uncertainty about what they actually mean.

2. A Single Case: Abdelmohsen's dissertation

As demonstrated in the previous section, the comprehensive assessment of BIM usage in practice is scarce. The BIM empirical studies in the literature are either interpretations of historical data - questionnaires performed after the project was concluded - or software testing performed outside the office's environment,

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[25] Apparently UK still has the most advanced implementation of BIM. The vision for the UK Construction Strategy 2025 is currently requiring 4D BIM.

ignoring the day-to-day conflicts and struggles. This research was only able to find one ethnographic-based description of a BIM software being used while a project was ongoing: the PhD dissertation - "An ethnographically informed analysis of design intent communication in BIM enabled architectural practice” - written by Sherif Abdelmohsen and defended at Georgia Tech School of Architecture in 2011[26]. Abdelmohsen performed an extensive field research making use of methodologies conceived by social sciences that involves systematic collection of data based upon a participant observation. This short segment is devoted exclusively to review Abdelmohsen’s dissertation.

2.1 Abdelmohsen’s method

Abdelmohsen witnessed part of the design process of an 80.000 square foot building for a technical college of medicine. During a period of 7 months - between 2009 and 2010 - he observed the work of 7 experts: 6 designers with different expertise and one cost estimator. Abdelmohsen recorded and transcribed interviews with team members and meetings about design management, cost control, and design. His text portrays the laborious and painful process of design. The descriptions account for interactions among the conflicting views from different expertise, the conflicts between senior and junior professionals; the conflicting views of different stakeholders. The focus of the dissertation was on the role played by the BIM software - Revit - as a design tool: interviews performed by the author as well as the interpretations of meetings transcribed were concentrated on the performance of the BIM software.

2.2 Abdelmohsen’s case

Among the seven team members only one was able to work with the BIM software - Revit - a project architect referred as *the modeler expert*. Later in the process a second team member, *the design architect*, learned how to work with Revit but under *the modeler expert*’s supervision. In several segments of the transcriptions there are mentions to a frustration related to “the slow process of transitioning from AutoCAD to BIM”. The project Abdelmohsen observed was,

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[26] Abdelmohsen was advised by Professor Nancy Nersessian, a cognitive scientist that focused her research on understanding the cognitive and cultural processes that lead up to scientific innovation. It’s important to highlight that Professor Chuck Eastman, the author of the 1975 paper that originated the ideas behind BIM, as well as Professor George B. Johnston, one of the advisors of the present work, were both part of the committee of Abdelmohsen’s Ph.D. defense.

most likely, one of the first, if not the first project developed by the company using Revit. The dissertation did not account for the level of BIM proficiency, or Maturity, of its case study. However, considering that only one team member was able to work with Revit and all the other team members were relying on him to record design decisions, Abdelmonhsen's case falls between BIM Maturity 0 and 1 as per any of the models that were discussed in the previous segment.

Considering the arguments regarding interoperability and maturity raised in the previous chapter[27] it is reasonable to affirm that the design process witnessed by Abdelmohsen did not assess a BIM process. Instead it assessed the performance of the BIM software, Revit, as a design tool. The dissertation didn't explicitly distinguished BIM process from BIM software and the BIM model. This definition was only made at the conclusion, even so very briefly, when the author suggests that the object of study was, in fact, the BIM model. The distinctions between and among BIM process, BIM software and BIM model is a topic that deserves further discussion. While this text will not tackle these matters, it is nonetheless rational to say that by examining one of them, the other two will ultimately be studied as well.

2.3 Interpreting Abdelmohsen's work

Abdelmohsen's transcriptions and comments led to 3 distinct discussions:
- The MacLeamy curve contradiction
- Frustrations
- Affordances versus Limitations

The MacLeamy Curve contradiction

MacLeamy Curve illustrates the relation between cost and design-changes throughout the design process. The cost of any change on the design increases as the project becomes more developed, therefore a project becomes more difficult to change the more developed it becomes. In theory the BIM process enables major design decisions in early stages of the design process therefore reducing cost and speeding up the design process. The MacLeamy Curve is widely used by the literature as well as BIM software sellers to illustrate this potential reduction in

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[27] In order for the BIM process to happen all members of the team need to comply with the BIM software and in the same level of proficiency of it.

cost. Abdelmohsen's dissertation indicates the contrary; it shows that there is an increase in "cost associated with embedding too much information in the model and being forced to make design decisions at very early phases…" (pg 272). These early design decisions led to incorrect modeling and later re-modeling of the building elements. This is possibly the biggest contradiction among all claims about BIM achievements. Abdelmohsen's description revealed that the software did not allow design-decisions in early stages of the process; rather, it imposed them. The software was only able to deliver useful tables and schedules - area, costing, etc. - and functioning as expected if the model had been built with such a level of detail that contained building parts that could not be decided at that specific stage of the design. These early decisions forced the remodeling that led to delays and increase in cost. After the initial experience the team members avoided the exhaustive effort and cost of modeling completely in 3D to the nuts-and-bolts level of detail and agreed that the cost and time of modeling in such detail was not part of the scope of any discipline involved in the project.

Besides the remodeling process and increase in cost at the early stages of the design, Revit caused additional flaws at the advanced stages too. The excerpt below illustrates that the cost of modifications on the design in later stages of the process could be even higher than the predicted by the MacLeamy curve, when using traditional design softwares.

"(…)the more automated the process of data import and export becomes and the more complex the model is, the less likely it is that participants are aware of all design decisions or of any misinterpreted or lost information. Conflict detection, model checking and pre-checking methods often only add more automation and inhibit human intervention."(Pg 270).

Frustations

Abdelmohsen transcriptions revealed an overall frustration among the design team about the performance of the BIM software as follows:

- There was an ambition to perform design reviews over the BIM model. After a few attempts the team judged that discussions done over sketches and bi-dimensional print outs of the BIM model were faster and more efficient. Design reviews over the BIM model never really occurred.

- The engineer pointed out the lack of integration with engineering softwares and energetic-efficiency simulators and stressed that the same softwares were already fully integrated with bi-dimensional AutoCAD. This was the only segment of the dissertation where interoperability was briefly assessed.

- The main *architectural designer* complained that the Revit imposed too many constraints at very initial stages of the design therefore too rigid to be used as a thinking tool. The digital bi-dimensional environment of software like AutoCAD was similar to the hand-drawing environment, it had the freedom needed for developing thinking-sketches and at the same time allowed these sketches to be developed into detailed documents, all in the same digital environment. Revit forced the thinking to be developed outside the software, either by hand or in AutoCAD. Only when the sketches reached a certain level of development that they could be RE-drawn inside the Revit environment and modeled. The *architectural designer* also agued that working with Revit from the beginning, making and recording design decisions, took her much longer than making and recording the same decisions 'by hand' or in Autocad and later redraw it all together in Revit.

- The *cost estimator* considered the automated process of quantity take-offs unrealistic. The level of detail of the model needed to enable the correct withdrawal of data far exceeded the scope of work typically performed by an architectural practice. Additionally, automated take-offs do not imply the elimination of human error. A visual-analog check of printed drawings was still needed, much like in the case of drawings made by hand. For any BIM software, the data is still developed, modeled, and inputed into the software by humans. As well as 2D drawings, there are good models and bad models, and each will provide both correct and incorrect information however in different degrees. The statement of the *cost estimator* is evidence of an old philosophical matter: Perfection, either in modeling or drawing, is a myth.

Affordances versus Limitations

Although the transcriptions showed a greater amount of limitations versus affordances, there is a noticeable bias,[28] possibly unintended, that tended to minimize the extension of the limitations. In two segments of the dissertation the author considered as added values two limitations found by the research: when

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[28] Throughout the conclusion Abdelmohsen swings from affordances and limitations on each paragraph, instead of pragmatically list affordances and limitations separately, in a visually comparable way, and critically discuss the findings

the BIM model didn't behave as expected, the team was forced to meet in person to discuss, and this occasional meetings forced by the software failure was considered an important social glue, therefore an affordance of the software. Excerpts from the text are below:

Regarding discipline clashes:
"In principle, conflict detection and resolution methods were assumed to resolve all issues and conflicts among participants. This was not necessarily the case in practice, where there was a need among different participants for additional channels of communication external to the model to account for misinterpreted data or actions during the conflict checking process. Although this was considered as a drawback, ***it gave way for another added value, which was the social glue enabled by the tool.*** *The automated and seamless detection and resolution of conflicts among different participants – which was the expected value in principle – was not fully attained,* ***but the fact that those participants came together or communicated to discuss specific issues was an added value in practice*** *(…)* if the BIM model forced them just to come together to discuss the issues, without having an automatic or magical way to resolve them, that was sufficient at least to draw their attention, get them to engage in discussions with multiple communities accordingly, and realize the mutuality of their participation." (Abdelmohsen 2011, 273)

Regarding incomplete information:
"In principle, completely represented model data guarantees an efficient representation of design information and workflow among multiple participants. This was not necessarily the case in practice. Although complete geometric and semantic information was needed by most participants, there was an implicit need for having enough space to interpret that information and make meaning out of it. In other words, this ambiguity was still valuable in overcoming the overwhelming sense of automation in data exchange mechanisms. ***This gave way for yet another added value in practice, where participants got together, aided by brokers, to discuss ways to align their perspectives concerning the exchanged information through mutual understanding of their needs.****"* (Abdelmohsen 2011, 274).

Much like the literature assessment presented in the previous segment, Abdelmohsen's interpretation transcribed above confirms that the commercial aspect of this topic, BIM, is intimidating researches and academic journals to disclose realistic findings.

Abdelmohsen considered the BIM model “a repository that just documented an external design thinking process resulting from brainstorming sessions and design meetings.” (Abdelmohsen 2011, 269). This conclusion illustrates the simplified way the design tool was contemplated by the dissertation. Design tools are, by nature, repositories of external thinking. In other words, design tools should record and display the design decisions in a way that facilitate design modifications related to new design decisions. The flaw of Abdelmohsen case is that only one member of the team was able to work with Revit[29]. While this member, the modeler expert, was developing and recording his own design decisions, he was, at the same time, recording decisions made by six other team members, decisions that were developed through different supporting tools - hand or AutoCAD drawings. The ability of the BIM model as support for thinking, that is display information properly, was highly diminished considering this scenario, and it was completely dismissed by Abdelmohsen analysis.

The most relevant discussions raised by Abdelmohsen’s dissertation are (1) the cost and effort of exhaustive modeling so that the BIM software is able to respond to the fullest of its capabilities; (2) the reliability on software automation in order to identify design clashes and quantity take-offs; and (3) the understanding of BIM software usage not only as a repository, but also as a support mechanism for thinking. Abdelmohsen questioned the ability of a single platform to capture all the aspects of the design intent of a building; that is, storing external thinking (or design decisions). However, his text did not discuss the software’s ability to display these design decisions, allowing for their interpretation: the aspect of the ‘thinking support’ tool – the main object of this dissertation.

Different from the scenario observed by Abdelmohsen, where only one designer used Revit, the field observations described in the next segment of this dissertation was immersed in a setting where every designer and consultant used Revit to its fullest. Aside from the repository aspect of Revit, this setting allowed the observations to register and assess several design decisions by different

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[29] The architectural designer only worked with Revit at later stages of the design even so she wasn’t able to produce any relevant information due the rigidity of the tool. There are inflamed arguments between the architectural designer and the modeler expert transcribed in the dissertation however the author’s interpretation only contemplates social aspects of this discussions.

designers made over Revit’s interface. The field observations also tackled the extent of the modeling - potentiality and necessity - in order to meet the requirements of clients and contractors, as well as the extent of automation and withdrawal of data realistically possible. The text will also refer to the erroneous propositions defined in the second segment, as well as additional topics that emerged from the field observation.

SEGMENT THREE: Field Research, Ethnographic Observations of BIM Use in an Architecture Practice

In this last segment, I will present a case study that was conducted with the aim of responding to the questions raised by the two initial segments of the dissertation: What is the character of the architectural design process once BIM has been introduced to its fullest extent? Has BIM changed the architectural design process?

1. Object and methodology

During a period of 8 months - from March to October 2017 - I observed the work performed inside an architecture firm located in United States, specialized in senior-living projects[30], which I will refer to as SLinUS[31] (senior living in US). At the time of the research the firm had 60 staff members of which 45 were architects - managers and/or designers. The firm occupied one floor of an office building. Its interior was laid-out in an open-plan with six working-islands, each accommodating between five to nine individual workstations. The perimeter of the floor was occupied by meeting rooms, owners and senior-staff offices. The work-load was organized as follows: Project managers were responsible for several projects simultaneously, and each architect of their team was assigned to one or two of these projects, depending on the architects' experience and project schedules. The sub-consultants were external parties and the communication was handled through email or phone calls. Theoretically, the project manager and the architects responsible for her/his projects would sit in the same working-island. In practice, however, this didn't happen. The architects often moved from project to project depending on individual expertise and project time-schedules. Very often project managers and architects could be seen walking across the office searching for their team-partners.

Every project of the company was being developed in Revit. The software was installed in every computer assigned for design work and used by every architect-designer of the company. Every external consultant contracted by the company had a similar level of BIM proficiency. All project files were shared among the designers and consultants through a cloud based platform provided by Autodesk.

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[30] The so-called senior-living in US is a private development aiming the senior population. The complex includes facilities designed for elderly population such as specific amenities and medical care rooms. Its price is below the market however when the occupant dies the unit must be sold back to the original owner for an previously agreed price.

[31] In order to meet the requirements of the Institutional Review Board, the name of the company as well as the names of the people who participate on the research were kept in confidentiality by the author.

BIM was fully implemented. Among the staff, there was one architect entirely dedicated in coordinating BIM across the company, the BIM manager. He was responsible in guaranteeing the smooth functioning of Revit. According to the BIM maturity models discussed in the literature assessment, this company could score as high as level 3 on the NBS maturity scale, or BIM level 4 on the scale proposed by Succar et all, depending on the project assessed.

The ideal circumstance for an ethnographic observation of a design process is to track down the entire design process of one building, from beginning to end, registering the meanderings and procedures of every design stage. Due to timing constraints however, this scenario was unrealistic. The design and construction of a building takes on average five years, without considering the usual interruptions for legal approvals, budgeting adjustments among many other bureaucratic procedures related to the AEC industry. In order to keep the schedule of the PhD research I had to accomplish the field research in roughly 10 months. Following a single project during 10 months would restrict the observation of Revit functionality to very few stages of the design process with the risk of compromising the accuracy of the research. In conversations with the firm prior to my starting day it was agreed that I could observe projects in different stages of evolution and development. This was the only strategy that could allow me to comprise as many stages of the design process as possible to provide the best description of Revit functioning.

I was initially assigned to track down the work performed by seven architects that were sitting in the same working island. Not coincidentally, the projects developed by these architects were in different design stages. Projects developed simultaneously within the same company will very rarely be in the same design stage. Assigning me to a working-island seemed to be the most rational decision in order to facilitate my observations. I was also introduced to the BIM manager, he was supposed to answer my questions related to the functioning of Revit but not necessarily to be part of the observations. It took me around a month to understand the office’s routine and to identify, among this group of people who was really willing to spend time with interviews and occasional conversations. I was offered a vacant working station beside the BIM manager to use during the period of my observations. This desk was located right across the office from the island where ‘my’ group was sitting. The distance from my team turned out to be very convenient. It forced me to constantly walk across the office and induce situations for architects beyond my group to ask me to participate in the research. Only two out of the seven architects initially assigned were open to letting me observe their work; however, my trips around the office allowed the inclusion of three additional architects, beside the participation of the BIM manager, which became pivotal as the research evolved. I have tracked the work performed by five architects and the BIM manager. The projects and the design stages of each architects are described below:

Architect A- Convent renovation, Planning permit.
Architect B- Senior living, Design development
Architect C- Facade retrofit, Planning permit/ Senior living complex, design development
Architect D- Senior living renovation, schematic design/ Canopy of a building entrance, construction drawings
Architect E- senior living renovation, planning permit.

Besides the work performed by the five architects, I had two additional sources of observation: 1) regular visits the BIM manager received at his work-station from different architects looking for specific BIM consultations; and 2) meetings the BIM manager hosted every other week to discuss issues concerning BIM. The regular consultations would usually regard matters related to specific projects. The so-called BIM meetings discussed topics such as BIM standards, procedures, strategies for acquiring new versions of Revit, etc. The quorum of these meetings never exceeded eight people. The five architects already participating in my research were regulars, and two or three additional participants would attend occasionally only to clarify matters related to their own projects. These meetings and the BIM consultations were always followed by a very long and passionate speech of the BIM manager delivered privately to me. The meetings, consultations and speeches were registered with 200 hours of audio recordings in addition to a large volume of textual notes taken while observing designers working on Revit. This entire database was assessed and interpreted however only the most relevant fragments are transcribed and discussed by the following text.

During the first weeks of the field research, I tested theoretical methodologies for ethnographic field research[32] learned during the previous years in my PhD

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[32] Latour, Bruno (2005). Reasembling the Social - An Introduction to Actor-Network-Theory. UK: Oxford.
Guérrin, F.; Laville, A.; Daniellou, F.; Duraffourg, J.; Kerguelen, A (2001). Compreender o Trabalho para Trannsformá-lo - a pratica da ergonomia. SP: Edgard Blücher Ltda.
Geertz, Clifford (1973). The Interpretation of Cultures. NY: HarperCollins Pb, Inc.

course. I've attempted to describe subjects, actors, objects and roles, and develop interviews based on notes that were systematically taken and color-coded by actor and function. However the methodology taught by Professor Francisco Duarte in his course Ergonomic Analysis of Work[33] was the dominant model for observing a design process. I was taught how to observe an action or a meeting, distant enough from the action performed to not interfere but at the same time allowing the observer to register it by notes and audio recordings. Once the action was complete the architect was asked to describe it by answering three questions: (1) What were you supposed to be doing? (2) What did you actually do? and (3) How did you do it? The answers to these questions were then confronted by my notes, audio records and the literature. Many contradictions and discrepancies were found and are discussed by this text. The main actors in my descriptions were the BIM software Revit and the behavior it imposed on the design team. People and projects had a secondary role. The decision to consider Revit an active actor of the design process is a direct influence from Actor-Network-Theory proposed by Latour. However, Latour suggests that objects should have the same weight as the living actors, and the focus should be on the connections among them. Instead, I focused my observations on the object and the actions it induced.

The work performed by the group observed encompasses all the stages of the design process - schematic design, design development, planning permit and construction drawings. However, Revit neither strengthened nor weakened any design stage or project in particular. As the research progressed, it became apparent that the functionalities of Revit, its efficacies and flaws, evenly permeated all the design stages observed. Therefore, the transcripts are organized by topic rather than project or design phase.

2. BIM Functionalities and the Erroneous Propositions

The biggest conference room in the company had been reserved for me through the morning period of my first day of field research. I was to use the room

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[33] Besides his academic research projects, Professor Duarte has an extensive consulting experience in Ergonomic Analyses of Work. For the past 15 years Professor Duarte and his teams have been systematically commissioned by Petrobras (Brazilian Oil Company), among other companies, to study and implement improvements on the work performed. His consulting is based on prolonged site observations performed by him and his team and a later analysis and interpretation of the data collected. Besides the theoretical framework mentioned in this paragraph, much of the methodology he teaches in class comes from his personal experience from consulting work.

to introduce myself and present my research project. All the staff was invited to attend, including the architects I was already assigned to observe. The conference started at 9:15 am, there were sixteen people in the room. I spoke for roughly 20 minutes. At the end of the presentation I started answering questions about my procedures for collecting and registering information, but it didn't take me too long to notice some tension among the participants. It was when the BIM manager, without been asked, started a speech about what BIM was. His speech triggered a passionate argument among the audience. From that moment on, I kept quiet, let them talk among themselves and started recording. The audience was clearly using the meeting as an opportunity to discuss ongoing issues. It seemed that the staff was divided into two competing teams - BIM supporters and BIM non supporters. Below are a few fragments from the discussion:

BIM manager: *"There is a fuzzy line that is drawn. Revit is a tool, it could be BIM, it could not be BIM. BIM is a defined managed process that will vary depending on the typology of the project, owners needs and capability of the team. And that's when we sit to discuss. We are also sitting in a place right now where our owners and contractors don't need that super crazy data layered, nor they wanna pay for that. That is a separate discussion."*

Architect A: *"Revit is BIM because all the information and sketches are in the same file, the model. This is a differentiation from cad where the information is in separate files. When you have all the information in one file, this is the basic foundation of BIM."*

BIM manager: *"What bothers me is when people say 'model model model model' such as it was a virtual simulation of a building. We need to understand: this as a scientific model. A bunch of numbers that come from a multiple source: a spreadsheet, the Revit model itself, a cad drawing. All informs the model. Which leads to interoperability, which is a whole different discussion."*

Architect A: **"***Interoperability (laughs), it seems that we are having this conversation 20 years ago when everyone was coming with a different platform. In 10 years' time maybe a single company will take over and resolve it, I've seen contractors doing tri-dimensional coordinations, if we don't or can't do it doesn't meant it isn't possible.***"**

Architect B: *"To me that is the frustration about the design process in Revit, and we had the same conversation with CAD. It depends of the operator I am working with, and the level of detail they want to input in the model. When they demand me to define too many dimensions in a schematic design, to me this gets in the way of what we want to accomplish, which is just documenting a conceptual design. If it is a schematic design for pricing purposes or to present to the owner just for them to conceptualize the design, we don't need that much information. Even if we throw away the schematic design and start over, it still less time consuming. We do it for the sake of the operator."*

BIM manager: *"You don't have to do it!"*
Architect B:. "*I know but the operators demand it. There is a problem between conceptual design and documentation, but the design continues in between."*

Architect C: *"Another day I had a discussion about the thickness of a wall that was shown in the model with 4 inches but the drawings were showing it with 2 inches only. This was driving the entire conversation about a conceptual design. It is a huge disadvantage. I can use a thin pen or a thick pen to draw my wall and show the concept without defining the final thickness of it. We often have to input information and change it later on. I can feel the frustration of the operators when they need to change information and ask why didn't you gave me the correct information in the first place? I say: Well, we didn't know yet the sizes the bolts were!"*

Architect D: *"This is a constant battle. Just like when the interior design team say they can't put the light in the model because they don't know what that light is yet!"*

Architect E: *"…but we didn't know what we didn't know. We can feel the frustration of the operator."*

BIM manager: *"But things always get harder to change as it gets later in the process. whether is in CAD or Revit. If you wait until constructions documents to change, its gonna suck, regardless. But you can do as sketch. It is because it is possible to put this level of information in the model that people desperately want to put it. You can use a 6 inches wall or a 2 inch wall, you've got to use something. Sometimes you need to remodel everything, sometimes you need to remodel only* *part of it. In reality there is a big chasm between the design model and the construction model. We can hand over our model to the contractor and they will struggle a lot because the model won't do what they need it to do! There is a lot of theory versus reality. Sometimes we need to start over because it makes more sense. We can train people to make the transition from design model to construction model but it takes a lot of software deep knowledge and I don't really think it make sense."*

Architect E: *"I would argue that the real model is the constructed product and has nothing to do with the BIM process at all. The BIM model is just intent."*

BIM manager:

"You nailed it! We are creating a design intent, and documenting it the best way we can. We are adding layers of data the best way we can. The reality is that we can't model with that level of detail. Nobody does that, it is insane. That drawing you showed me another day showing LODs 350 or 400s? It's got individual CMUs[34] !!Nobody does that, even contractors don't do it. It is absurd, time consuming, insane."

Architect A: *"Although I have worked in a project where the contractor modeled every piece of wood and fabricate it. And labeled in such way that once it arrived on the construction site it was scanned to give the information of where to put it and had the model open in the iPads to know where to put it."*

BIM Manager: "*Yes, but they were not us!* When you say "us", you not saying just the architect right ? You mean the contractors, the subcontractors. They were all part of the "us"!

Architect A: *"Hold on, there was a design portion of it. We delivered the model and they advanced it. The sub-contractors turned the model in their use. In that part of the country the subcontractors are already using BIM for fabrication! We should meet weekly, to update the model, at the end of the process we should have the as built to give to the client. And then the client would choose a FM*

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[34] LOD350 stands for Level Of Development 350. It measures how much detail has been modeled. CMU stands for Concrete Masonry Unit. It is a concrete brick.

software to use. At that point the model would already have all the components they knew it would need to be replaced. Well, It was their grand idea and goal. We delivered the design intent and the contractors took advantage of our models. At least the first 2 steps followed through on that, the design process and the construction process followed through on that too and then it got to the owner's hand."

BIM manager: *"OK, but that was a defined process. The BIM process was defined at the beginning of the project. Let's say I want to use RFID*[35] *tags to geolocate the pieces of structure at the construction site, but that is not us! None of that benefits us! "*

Architect A: *"Ok, that was a super special project, a federal project. We had specifications in the contract that we needed to deliver that specific kind of model."*

The discussion transcribed above illustrates two subjects: the misconception about BIM functionalities and the overall in-satisfaction with the level of detail induced by Revit.

Architect A's commentaries illustrate a general misconception about BIM's applicability and functionalities, subject discussed at the second segment of this dissertation. He described a project he had been involved with, where the contractor fabricated parts of the building using data provided by the Revit model, and geo-located them on site using a tag system. Later in the process the owner should have received the model as an as-built document for Facility Management (FM). Architect A and the BIM manager dismissed two facts related to Revit's applicabilities: (1) the Revit model had to be imported into the appropriated softwares for both, fabrication and FM. Neither of these functionality were performed by Revit; (2) a Revit model that responds to the standards required by Fabrication and FM software has to be specially commissioned for this purpose. At the end of his talk, **architect A** admitted that the project was a special case, developed for the government. The contract and the fees demanded the architects to deliver the model according FM and Fabrication requirements, including the weekly reviews for updating the model that these functions require. Meeting these Revit model standards is neither the scope nor the expertise of design companies.

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[35] RFID is a identification system for tracking purposes. It stands for Radio Frequency Identification Devices.

These standards are only delivered under exceptional contractual circumstances and the according additional fees. According to the excerpt taken from the BIM manager's commentary, producing a Revit model that meets these standards require computational knowledge that does not belong to designers' expertise:

"We can train people to make the transition from design model to construction model but it takes a lot of software deep knowledge and I don't really think it make sense."

Interestingly, managers such as **architects A** referred to the junior architects as "operators". Architects coming out of college into their first jobs will usually perform the role once performed by the draftsman, a supposedly extinct profession. Before BIM was introduced, these young architects were still called 'architects', or 'the architects doing the drawings,' and they had some decision making power, although little. This shift in terminology suggests an absence of decision making power, it refers to workers of industrial processes who were only allowed to operate machines.[36]

3. Over detailing of Revit files

The examples described by the **architects C** and **D** - the specifications of walls or light fixtures - suggest that the level of detail induced by the software is inappropriate for several stages of the design. The **design intent stage** that this group was referring to is a set of drawings used for a series of purposes: discussing the project with the stakeholders, pricing and bidding, and planning purposes. Details such as specifications of walls or light fixtures are not part of any documentation intended to this kind of negotiation. In a bidding process, for instance, the specifications should be as generic as possible in order to allow the bidding participants to suggest the spec that best fit the budged and goal of the project. It doesn't mean that these specifications are inaccurate or don't carry the design intent. They should contain all the accurate dimensions, intended materials, etc. but without suggesting any specific brand. The same rationale applies for planning permissions. A project granted with a permit by local authorities[37] should

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[36] This topic, changes in the architecture profession, is discussed in depth by Professor George B Johnston in his book "Drafting Culture".

[37] Construction works that impacts surrounding areas will require permission from local authorities. The local authority responsible for evaluate the project and grant the permission will vary from country to country as well as the process is given different names. In England the process is called planning permit. It is judged and

not impose specific brands for the building parts. It might suggest that the public sector is favoring a single company and not letting the market choose the best product. Besides, construction may take a while to start, and by the time the part is to be put in place it might not even be available on the market anymore. The design process is a sequence of negotiations that are susceptible to change even after the process is completed: part replacements, renovations and or reconversions are current practice of every building. The ideal design tool should guarantee precise and smooth negotiations at any time of the process.

Over-detailing of Revit files was also a topic often treated at the regular consultations at the BIM manager's desk. This excerpt below is one example among many where the BIM manager is asking a junior architect to use a simplified version of a building object, in this case a door:

BIM manager: *"There are too many parameters in the door-factory objects! They are dealing with things that we don't care at all! The door dimensions were considering the microscopic gap in between the door and the frame! We are not modeling that!! Nobody models that! All the undercut parameters! You guys took it way too detailed. We need a simplified version of it! . So, I am gonna do a simplified version of windows too for you all to use it instead the factory-object!"*

4. Interoperability and maturity

Maturity models suggest that projects developed by stakeholders that have the same level of BIM implementation would be highly efficient. However, the excerpt below demonstrates otherwise. Even though the companies involved had the same level of BIM implementation, individual software setups have greatly impacted the progress of the project. The following dialogue was taken from a BIM consultation at the BIM manager's desk. Architect A reported to the BIM manager a recurrent flaw in many of the projects he was involved with - building parts modeled in Revit were ignored, by the same software, when the model had to be opened and used by an external consultant.

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granted by the local Council. In US the same process is called building permit and it is granted by the County. In Brazil the process is granted by the city hall and is called "approval by the city hall". Different local authorities will have different requirements, related to local demands and safety issues, in order to grant a permission for construction. Although the process is different from country to country, its nature is the same, any medium to large scale project will need permission from a local authority in order to start construction.

Architect A: *"We always think that if it is in the model it is there, but if they don't see it, it is not there. So what they actually did was, they went back to the printouts, took out a highlighter and they highlighted all the missing parts! Because they have ignored literally hundreds of thousands of dollars of fire-ratings. And this happened many many times."*

BIM manager: "*This is one of the drawbacks of the model, there are a few ways we can view the model, they will link our model to their model but if their model is not setup with the exact same parameters, exact the same filters as our model, they will never gonna see what we see! We went through this thing of creating color-coded fire ratings for all the walls but it only show in our model because of all the filters and parameters we have turned on***"**.

In this occasion the BIM process did not facilitate the data exchange as expected. It had created an additional task in the process: double-checking the model by cross-referencing it with printouts produced from the correct BIM model setup.

5. The Cloud and Coordination - an analogy with traditional process.

The conversation below was extracted from a BIM meeting. The following transcript illustrates a communication flaw with external consultants.

BIM manager: *"Our file does sync to the cloud, everybody can see your synchronization regardless where they are. However it does not update the version of the model even though the date is sitting up there in the cloud, so when the consultant download the model, they are downloading whatever the hell it was there at the beginning of the project. I was going round and round with the consultants on this and it was like: "I don't understand why you are not seeing what I see from my end. And then today I downloaded from the cloud and opened it in my computer and boom, it was a version I uploaded two years ago! so I called Autodesk and they said we've got to republish the model! It is not only upload it from our end for whoever download from their end. It is not rational. There is a sneaky little button on the window 'collaboration' for Revit that says 'republish it', And that is not terribly clear written in the Autodesk work flow. When you open the cloud models you will see all the old models but everyone needs to sync and republish it in other to keep the "downloadable" model up to date. The external* *people will only see the most recent published. From now own we agreed to republish our models every Tuesday, wherever they are on the evolution stage"*

This fragment above describes a file-sharing operation in practice, a BIM-associated procedure that could potentially facilitate the management of the design. File-sharing is possibly the most important requirement for qualifying as BIM level 2 at NBS maturity scale (or 3 at the scale proposed by Succar et all). The smoothness of file-sharing process is associated to the topic Interoperability. Interoperability concerns the data exchange among different platforms as well as the data exchange among all the stakeholders, especially the design team. Maturity and interoperability are therefore interlaced topics. Although the company's BIM maturity could score level 2 at NBS scale, the interface of the platform was still not intuitive enough to let them to perform ordinary operations associated to the BIM level the company was proficient to perform. After extensive research the BIM manager identified the problem and found the solution; however, this solution may not be permanent. Solutions and standards are usually applicable to a specific software version. Newer versions will require different solutions. The next fragment was transcribed from the same BIM meeting. It is a discussion about the acquisition of a new version of Revit and the possible re-work that this new version will required.

It is important to highlight that file-sharing is not a feature restricted to the digital environment. Before computation, the blueprints also had to reach the external consultants and stakeholder, either by mail or other analog transportation. These blueprints were put underneath tracing paper and used as a reference, the base file. This reference would be updated and sent back to its origin and other consultants for further development. The newer electronic versions of file-sharing are far more efficient, yet they still performing the same role. The flaw described above lasted for two years before the solution was found. Meanwhile, the team had to use alternative paths to deal with the problem. The relevant enquiry that this circumstance implies is: To what extent was the technology a barrier rather than a benefit?

6. License System and documents standards

The following passage, extracted from the same BIM team meeting, illustrates the difficulties and challenges of migrating to newer versions of the BIM software.

Company's partner: *At the risk of creating more work for myself, recently I came across a thing that I just wanted to share with the group. I think I found that the 2018 Revit version is going to allow one version back. I think we might be able to keep the 2014 version. I am telling you this because I fear for land planning. They are gonna be thrown at transferring all this CAD standards from 2014 to 2017 and them to realize they could have gone straight to 2018. If this is true let's go ahead and get the 2018 version. Not that you guys need to do anything with that just yet. You don't even have to touch it if you don't want to.*

BIM manager: *This will give us some run time, we normally wait for about 6 months anyway to make sure all the services packs can be out. They are getting better because they are doing pre-releases now.*

Company's partner: *The problem now is that they are doing this every year and it is not even enough time for us to create our standards for that particular version.*

BIM manager: *That is a constant process, even within the same version but if I get it in my machine at least I can plan to create things that are gonna work for both. By reading the reviews on 2018 it seems that there is none of WOW factor, it is mainly stability improvements.*

Company's partner: *Well at least we can get the license, as it is out there, get time to people to get these 2014 projects off 2014. How long would take you guys to migrate?*

Meeting attendants: *A year, maybe more.*

BIM manager: *I mean, if there are a few improvements, ok. We might go for it but as per what I read, there isn't nothing really updated in this 2018 version, if we skip it we would not lose much.*

Company's partner: *The problem with this licensed software, we lose the license if we don't buy it every other year and we always need to drop from the previous version.*

BIM manager: *For example, we know for a fact that text have changed a lot from 2014 to 2017! I had to go through every legend, key, label etc. The fonts were different, spacing etc. So suddenly screw up texts on every drawing!! Everything was like over each other. They allowed things like copy and paste from work but, still not as good as old AutoCAD but, it is an improvement.*

Architect C: *You know it is rigged, just rigged you do everything to look right but if you touch it, it screws up everything.*

The licensing system discussed in the fragment above illustrates many layers of the innovation paradox suggested at the literature assessment: *Society is facing a new condition where digital innovations are happening at such speed that it does not allow enough time for a new technology to be learned, used and adjusted according practice.* Every new version of Revit seams to require a period for learning and adaptation, that is re-configurations, re-developments of standards and procedures, etc. According to the BIM manager's comments, some Revit versions could be ignored. Revit's new versions not always includes relevant improvement. However skipping a specific version may imply in losing the license and the additional costs associated to renewing or buying the license again. The frequent releases with insignificant improvements in software versions raises suspicious whether to be an unscrupulous legal device to increase sales and impose fidelity.

In many occasions throughout the 10 months of field research, the BIM manager have made reference to *"the good old AutoCAD"* as the ideal standard when compared to Revit. He was usually referring to features for page layout(ing), not included in Revit, that were imperative on pre-BIM platforms. The purpose of Revit is to produce the contractual documents, that is a set of bi-dimensional drawings. In Revit, a plan is extracted from the model while in CAD softwares, plans had to be drawn one by one. Some of the advancements accomplished by the 'pre-BIM' platforms such AutoCAD, were lost, however. In Revit, the features dedicated for page layout, text, line weight are overly inefficient when compared to pre-BIM platforms. Simple tasks such as positioning a drawing inside a paper sheet or editing and copy texts across different drawings are complex and inaccurate tasks to perform. The result is that the standards of drawings produced by Revit, supposedly its final product, are much lower than the drawings produced by its bi-dimensional predecessors. The time consumed by these tasks, due to the complexity and inaccuracy, as well as the quality of the final drawings produced should be considered additional units for measuring BIM efficiency.

7. BIM Functionalities - Facility Management and Design Management (the contractual documents)

The Revit file - the model - can provide data that can be used for Facility Management when specially commissioned for these purposes. The primary purpose of a Revit file at SLinUS is to develop and generate the contractual documents. Yet the clients of SLinUS were increasingly coming to expect that the Revit file, developed throughout the design process, could respond to Facility Management requirements. They ignored, however, the additional costs of these specially commissioned and produced Revit files. Intending to temper their clients' expectations, SLinUS partners called a meeting with the BIM manager to discuss the implications of including the final Revit file in the contractual document sets. The fragment below is a dialog between the BIM manager and Architect D that happened right after the meeting.

BIM manager: *Just came out of a meeting with partner M about contractual stuff. You know what, I actually like this kind of stuff!! I hate to tell you."*

Architect D: *"Really?*

BIM manager: *I love finding loops and closing them, and accidentally creating more looping, which is why it goes back and forth between me, partners J and T and me again. Everyone gets a different set of eyes, different opinions.*

Architect D: *What was it about?*

BIM manager: *It was all about this game of cat and mouse, and this electronic file transfer.*

Architect D: *You mean the model?*

BIM manager: *Yes, well when we share a model with the general contractor, or the owner - typically we don't do that - it is not in our contracts. Our contracts are about creating paper. We create PDFs we create Plans, etc. Those are the contract* *documents. We have not yet had any type of BIM agreement or IPD (Integrated Project Delivery) agreement that stats that they need a model for management facility or anything like that. We are obviously using the model to create the documents, at the same time we also want to disavow our own knowledge of the model that was used to create the documents, because the documents are the official thing. If we share the model with someone, with all these asterisks thrown on it and say "you can have the model but… don't trust the model, don't use the model for anything besides just looking at the model. Don't try to do quantity take off the model. We didn't do the model to do quantity take off. We did the model to make the documents and doing so we may or may not have modeled all the things that we needed to model to throw it in a piece of paper." That is why we have Details, that's why Revit has 2D lines. It is one of those things where I know the level we are modeling to in most instances but if someone want to use our model to count the number of windows, I feel pretty sure about that, we are not faking windows, but there is the instance where we might have had to do a window as a piece of special equipment for some reason because of something. So the counted one would be off and until we have an agreement where I am working hand in hand with the general contractor and the owner, as a team, the three of us are sharing that type of thing - "oh hey by the way guys we have model this to make this work, because we couldn't model it the other way whatever…" - And that is the kind of discussion where we can take the decisions to model in certain way that allows things like quantity take off or specific analyses etc. Because to achieve that we've got to think differently.* ***That is because we don't have the right tool to model it appropriately****. We are doing BIM BUT… It is a big floating asterisk by my head…****We are not really doing BIM, we are using REVIT to create contract documents which give us BIM capabilities of which we're not really harnessing all of the BIM capabilities because we are not contractors mandated to harness all of the BIM capabilities.*** *But why do we waste our time doing it? Hummm, yes you can have our model but it is not really BIM and it does not suit your purpose. You can use it as to "eyeball", as a supplemental type of thing, the documents are, still our contractual documents. It is also a liability thing "look you can use the model but by the way don't use it for anything or you can use it but… at your own risk. If you need to take any numbers you will need to double check on paper, old school.*

The reason we are not doing BIM is not because we don't want. When we break down the costs to build a model that suits the client's - owner's management *facilities needs, they don't want to pay for it. It can increase from 50% of the cost of the project up to as much as the project itself. Depending of the complexity of the project it can double the cost.*

Architect D: *Why is the cost so high?*

BIM manager: *It is about pure data entry. It is time consuming. It is got to get in there somehow and the only way to do it is with people! I can put an intern to do it, but still. It is time-consuming and to get the right data, on the right time it is also another challenge that may screw the whole schedule. The other point is, an architectural project is a design intent. Many things need to be decided much later in the process. Doors for example, we specify a kind of door. There may be 3 or 4 door suppliers that can offer this specific door. By the time the doors will be put in place some of the doors we suggested may not be available on the market anymore. There is no way to know the final decision of some details, it is the contractors call. This is the nature of this industry! Even with brick! We specify the color and we give them 2 or 3 manufacturers that provide this color but, it may take 3 to 5 years for the contractor to purchase the bricks, and by then, we don't even know if the manufacturer will still exist! Even when the contractors are on board from early stages. They are not making any decisions about doors or bricks or windows. Even if they were designing they needed to be talking to the manufacturers and come to us "look we talk to this much of manufacturers and we got a really good deal with this one and we gonna go for this one". It might happen in a IPD situation where you got the owner, the contractor and the architect, all three as a team working together. But that is rare!!! I don't know how many buildings I have done that way but not many. If I could have that much of date to input in the model at the beginning of the process, that would make viable to deliver the model as a checking object, but the cost behind that is absurd. So on our contracts we give the model but we state, "you can't make copies of it, We don't assure the completeness and accuracy of the model – because the model was made to generate drawings, again I may have 2D objects that only shown on 2D drawings but don't carry any more relevant data. They all ask for the model. We always ask why they need it and they always say: "I 'm gonna make quantity take off", so we ask "have you done it before?" And the answer is always: "no"! To make a model that is accurate enough to take quantity take off it will cost a fortune. Making certain decisions early on the process, tracing down the numbers, adding the data. It still taking a lot of effort. Still a lot of money.*

The transcript above illustrates in practice the Erroneous Proposition Two identified by the literature assessment: that FM is a function of BIM platforms. At SLinUS Revit is used to develop the bi-dimensional drawings included in the contractual documents and manage the process through these drawings. A Revit file suitable for FM will require data that will only exist in very late stages of the process, usually during construction work. The acquisition of this information in advance requires design decisions to be taken ahead of its natural time. These early design decisions are only possible in highly collaborative IPD agreements. These integrated agreements imply in additional high cost, even though they still not guaranteeing that the decisions will remain unchangeable throughout the process. Any design decision is susceptible to change until the construction is complete, regardless the level of integration of the process. This is the very nature of the design process.

It is interesting to point out that the BIM manger didn't consider that SLinUS was 'doing BIM'. He only perceived the BIM process when associated to FM of Fabrication, although the software itself does not perform either of these functionalities. The production of drawings was, in his view, an CAD software equivalent function.

A few days after the dialog transcribed above one of SLinUS clients expressed interest in commissioning the Revit file to be used as source for FM softwares. The BIM manager started to work on a brochure about 'Revit file for FM' to present to this client. The same brochure would serve to sell the service to other clients. When the brochure was ready for the presentation he came to my desk to show it and talk about the new venture:

BIM manager: *I think this might interest you, one of our clients officially wants the Revit for FM! I'd want to take the opportunity to start offering this for other clients! So the way it works is that any* ***facility management data*** *doesn't come during the design time. It comes during construction, it is the contractor that picks the final HV/AC units, elevators, etc. They collect all the warranties, manuals, things like that. This is part of an as-built model, and we, very rarely, deliver it. After the design leaves our hands, it is the contractor that does all the final coordination, final drawings, final everything. They are in control of the final as built. If I can get out ahead of the curve, offering all these services. The client is a hospital group* *and these guys have three campuses close to us, but they have a multitude of campuses across the country, if we start here there is an opportunity to expand it. Imagine what they have now, multiple campuses with paper plans that dates back from, I don't know how far back, but at this point they might be completely inaccurate. You know, hospitals, airports or whatever big program it is, they are constantly changing, shutting down spaces, creating new ones, buying new equipment, etc. They are going to be doing renovations constantly. So during the design meeting they told us that they want to "go digital" get rid of the paper plan situation! So the challenge was to tell them what that means without scaring them and bring the project to us. So the idea is to bring everyone, contractors, sub-contractors with us and we work as a team to produce and collect existing data. Not only dimensions but also specifications etc. We would be responsible for compile the date and from then work with them as a partner in a long-term run.*

The client was very excited at the beginning, however when the cost was presented the client declined.

8. Management of The Design Process (coordination) - The Primary Function

As already discussed, the primary function of BIM software is the management of the design process, therefore the use of BIM is expected to improve this management. These transcripts below will illustrate one of roles of BIM on management of the design process, also called coordination. These fragments were registered in two different occasions. In both occasions, Architect M and the BIM manager were working on Revit screens while discussing the task they were performing.

Coordination 1

Architect B: *Look, these columns should go like 2, 2.4, 2.8, 3.2…. But they don't match, it is really confusing.*

BIM manager: *I really think these guys are over worked. We bring their model into our model and, somehow they don't match. The columns are not aligned, there is a wall that doesn't exist, and this wall slightly offset makes me mad. It is just bad coordination, really bad coordination, it is actually not a Revit issue, it was like in*

AutoCAD, just bad coordination. Walls are completely in the wrong spot! They overlay our plans, model and boom…This is a basic stuff, this is not Revit, It is just extremely bad coordination.

Coordination 2

Architect B:

There is coordination. Things that we need to think about like agreement on Revit standards. Everything from naming standards to how often we look at the model. Who will own or host the grid, which is usually us. We set up the grid because we know where our building is gonna be, we know where the structure ideally needs to go. Any adjustment is noticeable by every one that is sharing the file. The coordination is just a matter of communication between the disciplines. The software facilitates communication but the matter is really about good communication, rely on syncing the model correctly etc. The biggest problem is with plumbing. They are always super minimal, the design is very diagrammatic. They show what is and where their stuff go but whatever happen behind the walls and ceilings, it is up to the contractor to find the most efficient, cost effective solution. But with the BIM model "over the table", the contractors are naturally assuming that all the pipes, joints, etc, are there, in the model, but no one actually models it. Some sub-contractors don't even coordinate among their own disciplines. The biggest problems are in the ceiling. AC engineers for example, they can't figure the clashes within their own projects. They constantly send drawings with cooling and heating pipe-vents on top of each other, assuming we, the architects, will fit them in between the ceiling and the bottom of the slab above. When we work with good consultants, they will send us plans, but usually they don't.

The main purpose of any design tool, regardless of whether it is BIM, CAD or traditional hand drawing, is to support and facilitate communication among the design team. The level of proficiency attained at these tools will influence the smoothness of the process however accuracy and completeness of the information are mandatory for its progress. Imprecision and lack of information are often associated to human error rather than to the tool or to the coordination procedure. The procedures didn't change much since before computation. For instance, the ancient blueprint copies of hand drawings were put underneath tracing paper and used as reference for creating a new drawings. CAD softwares had features such as 'external reference' that allowed drawings to overlay for the same purpose, mimicking the tracing paper. Although the Revit adds a third dimension to be overlapped, both procedures illustrated above were performed in two dimension - at the plan. I asked if there was any coordination procedure that could make use of the tri-dimensional view. The answer was negative. They said that the 3D views were distorted and confusing and prevented any accurate task to be performed. There are obvious advantages of CAD platforms from the 1990s over traditional hand drawing processes (Pereira et al 2016), however the advantages of BIM over CAD are still a conundrum. As discussed at the literature review, performing the same project, at the same time, under the same circumstances using both platforms - BIM and CAD - simultaneously is the only way to measure the benefits of BIM.

9. The Bi-dimensional Aspect

Besides recording the BIM meetings and BIM consultations, transcribed and interpreted above, I also observed architects using Revit. My observation procedure was to sit in a position that allowed me to have a complete view of the computer screen, however without obstructing the architect's workspace. In this position I also had a chance to witness a few short design reviews performed over the computer screen. The most curious fact I noticed was that the computer screens always displayed bi-dimensional drawings. Occasionally, architects would refer to a 3D view for illustrative purpose only, the design tasks were always performed over 2D plans, similar to CAD software procedures. The occasions transcribed below compile the several hours of repetitive Revit use witnessed.

Occasion 1
Architects D and A were performing a design review over Architects D computer screen when I approached them. Architect D was working on the computer while Architect A was pointing to the screen and making comments. After a few minutes, I asked about the 2D aspect of Revit. The architects had diverse opinions.

Architect D said that Revit provided 2D tools to facilitate the detailing of some building parts:
Sections are taken from the model and are completed with 2D CAD-like lines provided by Revit. The later versions of Revit had already acknowledged that some building parts are not worth modeling due to its complexity, a bi-dimensional representation was more efficient.

Architect A was a manager, he didn't use nor he needed Revit for his role. His contact with Revit has been only during design reviews, he's views of Revit were based on theory rather than practice:
It is a tri-dimensional thing, Another day I was looking at a roof in the tri-dimensional model, it looked completely wrong but when I opened the plans, the plans were right. Parts of the roof was drawn in 2D. It could not be seen in 3D. It was like we were cheating the system."

Architect D was the most proficient Revit user of the company. He argued that Revit's main purpose was producing the bi-dimensional drawings included in the contractual documents, not much difference from CAD software, any other theoretical function was peripheral. The model, in his view, did not need to be consistent as long as it provided consistent documents.

Occasion 2:
Architect E was using a printed drawing to identifying clashes between light fixtures and the ducts of the heating system. The paper drawing was illustrating the space in between the ceiling and the bottom of the slab. She was using a thick marker pen to highlight the parts that needed to be redesigned. I asked her if this task could be performed by Revit's automation. Her answer is below:

Clashes are invisible in Revit's 3D views while a trained eye will catch it instantly in a single drawing. We had a 100,000 dollar loss in a project just because we didn't see a hole in the ceiling on the Revit model!

It is assumed that Revit's automation can identify design clashes, however this feature is not embedded in the software. Automations needs to be written for each individual circumstances and requires advanced computer coding knowledge that does not belong to the architects' realm. Even when this level of automation is achieved, a traditional analog check is still required.

Occasion 3:
Architect C had two Revit windows opened simultaneously on two different screens connected to her computer. She had a printed drawing marked up laying over her desk and she was adjusting a plan according to it in one screen while the other screen was displaying a 3D view of a small two story building. The building format

was being automatically altered as the plan was being manipulated. She looked very distressed and in order to shorten our conversation she start to speak before I asked any question:

I have a few hours to update it and its not gonna look very good. I need to have updated plans and elevations but, elevations aren't gonna look very pretty, I have to negotiate some spaces but that changes the elevations, and I won't have time to review the elevations.

In BIM software, the alterations made in any building part are reflected in all the drawings simultaneously, this guarantees the consistency across the drawing set. Not always however this consistency is beneficial for the progress of the design. At Revit these alterations are always made in plan. However, elevations and sections, as much as plans, also induce design decisions. For instance, a facade detail such as building height or window width that should match the context buildings in order to earn a planning permit; a piece of furniture that needs to fill the space between floor and ceiling that can only be designed through a sectional drawing; or the efficiency and fluidity of the internal layout that is only illustrated in a floor plan drawing. Elevations, sections and plans illustrate different priorities of the project. Necessary changes on either plan, elevations or sections will have implications in one another, but not necessarily beneficial. Negotiations between the priorities illustrated by plans, elevations, sections are the core of architectural design. Before BIM, elevations would, very often, be developed by a separate team, usually more experienced. The coordination between these drawings were crucial for the progress of the design. A set of documents that suits the purpose of a design review should illustrate all the different priorities and requirements of a project at the same time and the consistency across these documents will evolve as the project progresses. Producing fully consistent set of drawings on decision-making phases of the design will ultimately leave aside potential design solutions.

3D BIM modeling is built on a 'self-extrusion' of plans, which is subsequently stacked on top of each other. For instance, when a wall is to be drawn in Revit, its height must be input at a parameter window/box beforehand. While the wall is being drawn in 2D, the extrusion takes place at the 'back' of the computer's memory. The process is only displayed in the computer screen if the designer enables it to be seen in a separate window. This process does not apply to elevational or sectional drawings. Elevations and sections in Revit, therefore, came to be results of decisions taken into plan. This logic inhibits architects to design through elevational and sectional views, and the priorities illustrated by these drawings are thus not given the appropriate attention. Throughout the 8 months of field research, I have never witnessed an architect designing through an elevational or sectional drawing. The computer screens across the office always displayed plans and 3D models, though the latter for checking purposes only. On only one occasion, I witnessed a designer working over an elevational representation; however, the elevation was an unsuccessful result of decisions taken into plan, and the changes the designer performed were intended to make the building façade more ‘palatable’ when presented to the client. This potential loss of elevational and sectional views as a vehicle for communicating and designing is an unprecedented cognitive constraint.

CONCLUSIONS

Building Information Modeling is a popular topic in academic research and a technological trend in the AEC industry. However, there is a divergence between claims/expectations and practice. BIM is perceived as the holy grail of the AEC industry with the potential to accelerate the design process, increase the efficiency of the construction process, and therefore to decrease cost. In practice however, these claims about BIM are still unsubstantiated, and have resulted in unrealistic expectations among clients, owners and designers about its effectiveness.

It is not surprising that software developers overestimate the benefits of their products in order to increase sales. Marketing strategies based on hypothetical achievements are not unusual either. In order to identify realistic performance of BIM, research should be able to scientifically verify its behavior in practice, measuring its effectiveness under the realistic circumstances of an ongoing project, and thereby confirm or contest the marketing claims. The confidential nature of the industry, however, imposes a barrier that makes empirical observations almost impossible. As one of the founders of BIM has acknowledged, “The AEC industry is a competitive field and organizations are often reluctant to disclose their enterprise expertise” (Eastman 2011, 396). The few available empirical studies have also failed to expose their results (Smits et al 2016; Arayici et al 2018; Copping et al 2016; Jin et al 2018; Oduyemi et al 2017). The commercial aspects of this topic may be intimidating researches and editors to disclose realistic results. Rarely do research papers focus on exploring and exposing the limitations they uncover but rather balance the deficits with known affordances. The conflation of functionalities misattributed to a single-multifunctional tool has also contributed to a lack of clarity in distinguishing between hypothetical and realistic achievements of the differentiated functionalities of distinct digital tools.

At the present, BIM technology delivers less than expected and often less than claimed. Its advantages are not as obvious as the advantages of CAD platforms from the 1990s over traditional hand drawing processes (Pereira et al 2016). The benefits of BIM over CAD are still difficult to measure, according to Barlish et al (2012), because it is impossible to compare the costs and benefits between non-BIM and BIM projects unless the same project is carried out using both platforms, by the same team, at the same time. While such a research scenario is unlikely in consideration of both practicality and cost, it would nonetheless be the only approach that could guarantee reliable and consistent data for comparison.

Recognizing the four fallacious assumptions presented in the second segment of this dissertation is essential for progress in BIM technology. I believe that it is critical to educate clients and owners regarding the specific functions of digital design and the realistic risks and benefits of the technology in its present stage of development. I also believe that for any potential progress to be made, the concept of maturity should be reassessed and reformulated based upon evidence from empirical experimentation. Furthermore, the concept of interoperability should be acknowledged as a legal as well as a technological matter. Design is a social process that involves participants of different interests. Social processes demand communication, and the different interests of the participants demand different modes of communication. Relying, therefore, on a single communications platform, especially when this platform imposes strong legal and commercial constraints, will ultimately hinder the whole process. I believe that researchers and designers should conceive a different strategy, inside or outside the digital environment, to support the existing BIM software, but one able to overcome the legal and commercial constraints of software industry.

Besides the four erroneous propositions proposed by the literature assessment, the field research demonstrated the following:

The definition of BIM and its functionalities is still unclear among architects. The general perception at SLinUS was that Revit only performed BIM when responding to the requirements of facility management or digital fabrication. Meeting these requirements, however, demands computational knowledge that does not belong to architecture's realm. The creation of bi-dimensional drawings in Revit, that is the contractual documents, was perceived as a function analogous to CAD software. The accurateness and level of detailing that the software is able to achieve, the most sought aspect of BIM software, is perceived as an imposition rather than as an option and is also inappropriate for several stages of the design process.

Either due to its complexity or to the frequent new version releases, the platform imposes a permanent technical constraint, regardless the level of proficiency at it. For instance, matching software standards among different companies seems to be a very difficult task, as is exchanging files through a cloud platform - that did not happen for the first two years of a project. The new versions of software will ultimately imply newer procedures to be learned. The frequency of the releases doesn't allow for proper learning time. Besides, the updates may be insignificant from version to version, seeming to be an unscrupulous legal device to increase sales and impose fidelity.

A tri-dimensional digital simulation of a building that is able to generate bi-dimensional drawings on demand as well as to provide numerical information about the building parts are the main purposes of BIM platforms. However, the transcriptions demonstrated that these operations can't be performed at the same time by the same file. Certain building parts, when modeled in 3D can't provide the correct bi-dimensional view required for contractual documents. These building parts will therefore be drawn in 2D. Revit's latest versions are providing 2D lines to allow contractual documents to be produced correctly. These 2D lines don't retain the numerical parameters of the objects they are representing. Therefore, the extraction of numerical information such as number of windows and areas won't be correct. A Revit file that is able to provide correct numerical information about the building requires some building parts to be chosen in the early stages of the process ahead of their natural order. These early design decisions demand an enormous amount of integration among the stakeholders that can cost as much as the project itself, besides the additional risk of rework due to eventual changes at the late stages of the process. The projects developed at SLinUS are currently using BIM for producing the contractual documents, in very few occasions SLinUS was commissioned to produce a Revit file able to withdraw correct numerical information about the building. Their clients usually intend to commission the full modeled Revit file during the discussions to set contractual agreement but they decline when its costs are disclosed.

Although Revit produces a 3D digital model, its construction is performed in a 2D environment that refers to a 3D object in the Euclidian space, alike the traditional hand drawing and CAD methods. It is assumed that the digital 3D environment of BIM automatically detect clashes among design disciplines, however the 'clash detector' feature needs to be added to the software by advanced computer coding, an expertise that, to this date, does not belong to the architecture's realm. Regardless, the digital tri-dimensional environment, the procedures for coordination/management of the design remained the same since traditional hand drawing. Drawings are still overlaid for reference purposes: discipline clashes, checks and design suggestions. Decisions are still made over bi-dimensional representations. The main design tasks are not performed within a tri-dimensional space due to the complexity of the views and the distortion of perspective representation that prevents tasks from being performed accurately.

The construction method induced by Revit, that is extruding plans and stacking them on top of each other, guarantees consistency across the drawing sets. However, it prioritizes the plans over other bi-dimensional representations as the support for design thinking. The bi-dimensional environment of hand drawings and CAD software allow the decision making power to be spread evenly among plan, elevation and section. While in BIM, elevational and sectional representations are the result of decisions made in plan mainly, rather than a support for decisions themselves. Revit logic inhibits architects to design through an elevational view. The loss of elevational view as a vehicle for communicating and designing is an unprecedented cognitive constraint.

This work has shown that the BIM, the tool and the process supposedly created by it, has the same functions and procedures within the design process as its predecessor tools, CAD and hand drawing. The argument that modeling instead of drawing would revolutionize the industry is a fallacy - the design procedures continue to be performed in 2D. Its tri-dimensionality only has a database function. 3d visualization continues to be performed by software appropriated for this function. The technology has proved to be inappropriate for several stages of the design process, imposing new cognitive and technical constraints, already discussed above. The functionalities that provoked the over-expectations of BIM (digifab and FM) are not performed by BIM software. Even if they were, these functions do not benefit the design process.

The main purpose/function of design tools is to support design decisions. That is, to **store** and **display** the design decisions in such a way that they can be easily assessed, and then modified accordingly. BIM software is designed to **store** as much data as possible, resulting in a large database of building parts, measurements and specifications. However, the process of inputting large amounts of data in Revit is costly and is restricted by permanent technical constraints. Moreover, because the nature of the information required for the software to operate to its fullest only becomes available in the later stages of the process, the inputting of this information at the early stages of the process will ultimately entail redundancy in work later on.

With BIM, plans, sections and elevations are generated by cutting through a 3D model. This means that when a modification is performed in one of these drawings, the other two will automatically reflect the modification. Though this may ensure consistency across the design set, it also creates an interdependency among the drawings that will ultimately leave aside design solutions that can only be achieved when these drawings and the decisions they illustrate are developed independently. The negotiations among priorities/subjects displayed by these drawings – plans, sections and elevations – are the core of the design process, and consistency across the board should be achieved as the design evolves.

The 'self-extrusion' process of Revit prioritizes plans over the elevation and section. Therefore, the design decisions **stored** in the Revit's model mainly refers to the priorities and subjects **displayed** by plans. The priorities and subjects usually displayed and discussed at sections and elevations have limited attention throughout the process, and, therefore, less impact over the design. Elevations and sections in Revit are ultimately the result of decisions taken into plan.

In Sum,

(1) the amount and nature of the information required in advance for the software to operate,
(2) the interdependent relation among the plans, sections and elevations imposed by the 3D-model, and
(3) the prominence of the plans as support for design are some characteristics of Revit's interface that greatly restrict the assessment and adjustment of the design during the entire design process.

Flusser's Five Rungs model illustrates a conceptual evolution of communication throughout the history of humankind. He construed the evolvement of the tools for storing and displaying external thinking. Flusser's five rungs are as follows: actions, objects, traditional images, linear text, and technical images. He argues that society evolves toward higher levels of abstraction. That is, the higher the level of abstraction (of the tool), the higher the level of evolvement or sophistication. It is assumed that every new rung will imply advancement over the previous one. Flusser was able to fully account for the four initial Rungs - actions, manual tools, traditional images, and linear text. However, his historical period did not make it possible to comprehend the Fifth Rung – technical images. He was only able to suggest that the Fifth Rung could impose crucial consequences on western culture, however, without defining the consequences and how it would ultimately affect society. The first segment of this dissertation demonstrated that Flusser's Fifth Rung - technical images - did not imply cognitive consequences over critical thinking. In the case of the architectural design process, the Fifth Rung is represented by CAD systems. The segment also defined an additional Rung where relevant cognitive shifts could take place.

The literature assessment and the field research performed by this work demonstrated the cognitive consequences of this new Sixth Rung in the context of Architectural practice. In contrast to the assumption that some advancement would take place at every additional Rung, this work demonstrated that, within the architectural practice, the Sixth Rung imposes strong cognitive limitations that has already led to adverse consequences in the AEC industry. The most evident consequence is the lack of understanding of the purposes of the tool (there is no ambiguity about the purpose of a linear text, a CAD drawing, or hand drawing for instance). This ignorance about the functionality of the tool has led to an increase in time and cost for the design process, as well as potential impoverishment of architectural variety and quality caused by the cognitive constrains as discussed previously.

Considering the theoretical framework constructed to assess BIM performance, the object of this dissertation, the response to the research questions proposed at the introduction of this dissertation are as follows:

- What is the character of the architectural design process once BIM has been introduced to its fullest extent?

- Response: The ultimate significance and purpose of the architect's profession is to present the architectural object (any man-built environment) as an experiential mediator between culture and technology. Well-conceived 'places', both culturally and technologically, ultimately become the benchmarks for culture, history as well as well-being~~.~~ The design tool should enable the connection between technology and culture. Through bi-dimensional drawings and its complementary media, the architectural design process was historically able to respond to societal demands as well as human behavior. The enormous technical constraints imposed by the Sixth Rung, BIM, is increasingly disabling architects from performing correct and efficient assessments of the cultural aspects of society. The original role of the architect as a mediator between culture and technology is being replaced by the role of software specialist, a technological problems solver with no available time to dedicate to any kind of social or human assessment.

- Has BIM changed the architectural design process?

- Response: A simplistic response to this question would be: No. The commercial argument that BIM enables tridimensional modeling instead of bi-dimensional drawing is a fallacy. The digital file that will originate the 3D model is produced through the development of a bi-dimensional plan. The shapes created in the plan are being extruded somewhere inside the computer's memory. This extruded plan is rarely visualized and, when it is, it does not provide a visualization that is able to allow accurate design changes.

  The realistic response to this question is: Yes. BIM has changed the design process. As mentioned previously, design decisions in BIM are restricted to the plans. Elevations and sections only reflect the decisions made at plans. The topics and priorities that can only be discussed in elevations and sections are given much less attention than if they were being developed independently. This is a cognitive limitation with unprecedented consequences.

The answers to the questions that have guided this research raise new and even more fundamental concerns about BIM functionality and performance. The fact that the full promise and potential of BIM has never been realized is obscured by persistent fallacies perpetuated by commercial interests and marketing claims. A more pressing question, however, is whether the sixth rung of BIM performance, even if made possible through innovations in machine learning and cross-platform interoperability, could ever be objectively confirmed without dependable comparative assessments. Only then would we be able to measure whether true BIM has ever really happened.

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APPENDIX

Marcel Cadaval Pereira / Moura Duarte
Roberto Bartholo / George Barnett Johnston
The Sixth Rung

Introduction

The following text discusses the gains and losses of cognitive dimensions after the *digital shift*[1] and its impacts on the architectural design process, based on Vilém Flusser's "hypothesis that human civilisation has seen two fundamental turning points since its beginning. The first […] may be defined as 'the invention of linear writing'. The second […] may be called the invention of technical images". (Flusser 2000: 7)

Philosophical background

Flusser argues that society evolves toward higher levels of abstraction. The *task of transmitting knowledge* is what determines the level of advancement or sophistication. At the beginning of the book *Into the universe of technical images*, Flusser proposes a model for "knowledge transmission" that distinguishes five moments, or rungs, throughout human history where further levels of abstraction are reached. The five moments set out by Flusser can be summarized as follows:
At the first rung primitive people were immersed in a concrete world; knowledge was transmitted by actions. Very little or no verbal communication was expected.

The second rung is the level of grasping and shaping, when the human beings that preceded us began to design and manufacture tools to improve their tasks. It was the beginning of the acknowledgement of the cause-effect rationale.

"Third rung: homo sapiens slipped into an imaginary, two-dimensional mediation zone between itself and its environment. This is the level of observation and imagining characterised by traditional pictures such as cave paintings." (Flusser 2011: 7) These traditional images depicted

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[1] The research project 89+, run by the curators Simon Castets and Hans Ulrich Obrist, suggests the year 1989 as the benchmark date for the digital shift. Marked by several paradigm-shifting events (the collapse of the Berlin Wall and the introduction of the World Wide Web), it is believed that everyone born after 1989 has little or no experience in an "analog" world.

habitats, routines; they were read and interpreted as the cycles of seasons, day and night, birth and death. Per Flusser, it marks the beginning of mythical-cyclical thought.

The fourth rung is the historical level: the invention and evolution of the phonetic alphabet and the concept of linear text that allowed for understanding and explanation, the beginning of consciousness. "A zone to which human beings henceforth owe most of their insights." (Flusser 2011: 7)

The fifth rung has its beginning at the invention of photography and, later, electronic media: radio, TVs and computers. The second turning point in human civilization in Flusser's hypothesis takes place at this level. Flusser, as well as many other philosophers – Ivan Illich, Ernst Cassirer, Susanne Langer, etc. – credit the phonetic alphabet as a major factor that is responsible for the way we think, act and behave. Its replacement by other media as a vehicle of culture would have crucial consequences on western culture and existence, consequences on historical consciousness (Flusser 2010).[2]

Every *new level of abstraction* reached is added to the previous ones. Potentially, levels are never disregarded, and there is a re-balance of strength among them and a tendency to prioritize the later one. The appearance of rungs overlap and their strengths are constantly rebalanced over time. Although it makes no sense to attempt to build a historical timeline for the emergence of each rung, it is helpful to understand how the transition between them might have happened, especially in order to understand the implications of the fourth rung, linear writing, on memory and consciousness.

The first turning point: third, fourth and fifth rungs

Although it is impossible to know the specific time in history when homo sapiens started to communicate with each other through organized speech, not grunt sounds coming through the mouth, we can guess that it might have appeared sometime between the first and third rungs. The intention to record "communication" probably came not much later than the beginning of organized speech. Following Flusser's rationale, the first attempts to record communication were through symbols, and later evolved into a pictorial-ideographical record. The evolution of *organized speech* and its first recorded attempts into formal language brought together a level of abstraction, a new level of consciousness and memory: the mythical consciousness, as named by

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[2] Per Flusser's view, history has as many interpretations as the number of interpreters (readers). Their conflicting views evoke further interpretations, and this loop of evolving ideas is historical consciousness.

philosophers. Ernst Cassirer was probably the first philosopher to consider that a deeper understanding of myths was needed.

Myths, sometimes crystallized in dogmas or vulgar superstition, were always excluded from the fields of any philosophical interest: *theories of knowledge* were only concerned with the appreciation of facts. Ernst Cassirer considered human beings to be "symbolic animals", using systems of signs and expressions as means of communication. The ability to define meanings was a human instinct that enabled mutual understanding. This background established the conditions for the origin of knowledge, the more "primitive" forms that underlie the more sophisticated cultural expressions. Cassirer's work sets up a discussion about the dialectical process through which religion and art developed from mythical thought, and theoretical science developed from natural language. Per Cassirer, "Myth never breaks out of the magic circle of its figurative ideas. It reaches religious and poetic heights […] But Language, born in that same magic circle, has the power to break its bounds; language takes us from the myth-making phase of human mentality to the phase of logical thought and the conception of facts" (Cassirer 2014: IX).

Flusser pays specific attention to the *record* of language, and how it evolved into the reading and writing, we have known since the mid-twelfth century. It took around 3000 years for the alphabet to evolve and spread across society. The evolution of levels of consciousness can be noticed throughout the transition from oral to written transmission. "From the seventh until well into the sixth century B.C., reading and writing were confined, in Greece, to very narrow circles. In the fifth century B.C., artisans began to acquire the art of carving or engraving letters of the alphabet. But writing was still not a part of recognized instructions […] a full century before the stylus was imposed on pupils; they were able to learn the texts by heart" (Illich 1989: 23). Homeric epics and other books would be recited in their entirety by using mnemonic techniques such as rhythm and rhymes. The invention of the alphabet and its ability to record such works have induced a level of memory loss. A text, before memorized, was now attached to a clay plaque, parchment, and later, to a sheet of paper.

As well as the slow transition from oral to written transmission, writing and reading have also slowly evolved. At their appearance in the 7th century B.C., authors would write through the hands of others by dictation. Writing was a strenuous job (carving on a leather membrane or a clay plaque) until the invention of parchment and paper, and a professional *scribe* executed it. Around the 12th century, monastery libraries began to create catalog techniques in order to find manuscripts inside their archive. Texts were organized by theme, importance or date, and memory started to grow a new dimension. Texts were read aloud to an audience. Silent reading as we know nowadays was a later stage in the history of reading, and yet it was the most important transformation, the detachment of the text from the page, discussed by Ivan Illich in the book

The Vineyard of the Text. Although there was an evident loss in memory during the transition from oral to written transmission, the invention of the alphabet, silent reading, orthographic rules, and catalog techniques have given to humanity the ability to think critically, as discussed by Flusser. The phonetic alphabet, the fourth rung, gave us the ability to organize things in a specific order, going in one direction, not returning to the starting point. Only after the phonetic alphabet could cyclical thinking be overcome (Flusser 2010[3]; Langer 1984).

Besides the alphabetical order of organization and the idea of hierarchy, the alphabet has given us the ability to track whatever has been filed and consciously look into its internal co-relations in order to find logic and move towards the end of the line, the conclusion. As well as the organization of books in libraries, the subjects spread out over the pages of a printed newspaper and the location of typewriter keys, knobs on radios, vinyl players and film projectors, the analog world has been strongly driven by the alphabet. Flusser's hypothesis suggests that humanity is witnessing a second turning point, climbing a new step towards a higher level of abstraction, a new step yet unknown where critical thought might be reshaped.

"Flusser's original argument relies on its own historical period: the computers of that 'age' could only be manipulated by computer programmers. Interface platforms such as Windows or Mac OS would only be released years later, as well as software programs that would translate commands originally formulated in computing codes into commands adapted to ordinary users, with no knowledge of any programming languages. The idea of computer programming languages that would serve other languages could not be predicted yet" (Losso: FS 16). The general understanding during the initial ages of computing was that one would need to know computer programming in order to carry out a job/work/function in its most efficient way. However, it is important to acknowledge Flusser's efforts to understand the implications of computation during its embryonic phase: the black/green computer screens dependent on specific algorithmic codes in order to function, among other digital-technological advances. Yet, Flusser's hints about "the fabulous new way of life […] emerging around technical images" (Flusser 2011: 7) is one of his most interesting outcomes. What is taken by this work is the rationale with which his arguments are supported. In the digital "revolution" we are witnessing, the alphabet – writing – is taking a peripheral role, and touch screens and virtual tools are the bigger players now.

Flusser's writings did not consider the disappearance of writing, but its reshaping into an "algorithmic" format. Although the digital revolution did not reshape writing into a computing

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[3] Per Flusser's view, before the invention of the alphabet the world could only be understood as it was presented, without further interpretations. For instance, the repetition of seasons and their cyclical relations with plantation, the cycles of day and night, and so on. The returning to a starting point was a dominant idea, and the "images" presented (seasons, day and night) would not allow for many interpretations as a written text, and therefore would not evoke conflicts that would cause the evolution of a consciousness. Flusser calls it mythical thought.

code, the hypertexts, the filtering system of publishing, and the extensive reliance on iconographic language, among other examples, have given the virtual transmission of information a format that radically differs from twentieth-century writing and reading.

The sixth rung

Flusser's five rungs can be diagrammatically expressed as follows:

Actions – objects – traditional images – linear text – technical images (partially analog).

The traditional image is an observation of an object, and the technical image is a concept computed in an apparatus, per Flusser's definitions. The gesture of tapping with the fingertips on the keys of an apparatus, a topic extensively discussed by Vilém Flusser, is one of the concerns of this text. The problematics involving the technical images, especially at the beginning of computation, were determined by two considerations combined: (1) a technical image is an innovative way to express a concept. At the fourth rung, concepts were expressed by linear text, following a unidimensional rationale; (2) in order to express a concept through a technical image, one must learn a new alphabet, the computer codes, as well as be restricted to the possibilities of the apparatus, the black box paradigm.

Nearly 40 years after Flusser's writings, the need to learn a computer language in order to produce knowledge is not a reality. There was a shift in the black box paradigm, and the black/green computer screens populated by "new computer alphabets" were replaced by interfaces that tried to simulate the analog logic: the filing systems in virtual folders and their virtual trash, software for writing and drawing, etc. These simulations have become more and more sophisticated. The keyboard was almost completely replaced by mice, pens, tablets and, more recently, by our fingers. There is almost no need to use the alphabet, to write, in order to execute a function: we rely on our fingers' touch and iconographic information previously placed on the screen. It does not mean that the black box paradigm has ceased to exist; there are different levels of sophistication or intuitiveness within these different simulations of analog world. In the architectural environment, the subject of this study, the level of sophistication of simulations can affect enormously the social interactions alongside the design process. The black box is not a static barrier. There is a gradient characteristic within the barrier: layers of "intuitiveness" versus reliance on new knowledge as well as restrictions of the *apparatus*[4] itself. Vilém Flusser acknowledged that any technology is a potential transformative tool: “There is a complex feedback loop between the technology and the people who use it. A conscience in process of transformation calls for innovative technology, and an innovative technology transforms conscience.” (Flusser 2010: 39)

One issue that is embedded in the statement above is the reliance on someone else’s knowledge in order to produce knowledge. This has an evident effect on the design process. By design, I do not mean architectural or any other kind of artistic-creative processes only, but any kind of process that produces knowledge: art, science, and technology, as well as its management procedures. The gradient character within the *reliance on someone else’s knowledge* relates to how easy or difficult is to deal with *the* new technology. Exploring this gradient is a matter of a detailed ethnographic research project, and therefore is not the focus of this work. This text explores the possible transformations of consciousness by the use of *the* new technology. The architectural process, the *object* of the following lines, is only a familiar domain that I can comfortably use to understand the subject. It is my hope that the rationale behind this work can be applied to other domains.

Drawing = writing? The traditional architectural image

The traditional handmade architectural drawing would not fall into any of Flusser’s categories. It cannot be classified as *traditional* because it is not an *observation of an object*; neither is it a *technical image*, because it is not *computed in an apparatus*. The traditional architectural drawing is a handcrafted representation of a *concept*[5]. In this regard, the traditional drawing is equivalent to writing, as well as the text that, in order to be interpreted needs to be completed by the *next lines, paragraphs and pages*. The traditional architectural drawing needs to be completed by other media: texts, material samples, and other drawings. The traditional architectural drawing is a rational/Cartesian translation of a concept, as it is the text. Its linearity is not as obvious and visual. One reason might be that the architectural *orthographic rules* vary from practice to practice, from builder to builder, and so on. As well as in texts, the analogies, metaphors, hyperboles and other figures of speech permeate all the media throughout the design process. The architectural design process seen through the lenses of Flusser’s model can be described as follows:

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[4] Apparatus in this case refers to software and hardware and how they respond to each other.

[5] The word *Concept* may be misleading in this case. A concept in this case is anything that carries a displaced meaning. The answer to a question or a copy of an existing text can also be considered concepts.

- First rung (actions) – Client's briefing, site visits and any other essential social interaction.
- Second rung (grasping, objects) – Physical modeling, material and texture samples.
- Third rung (traditional images) – Traditional architectural image, as described above.[6]
- Fourth rung (writing) – Contracts, specifications and any other written means of communication.
- Fifth rung (technical images) – Images generated by apparatuses such as photomontages, airbrush renderings or digitally generated images.

As mentioned previously, due to societal changes and advancement in technologies, the complementary relationship among the rungs has changed throughout history. Actions (speech), objects (models, samples), texts (contracts), and drawings (traditional and/or technical) had different strengths in different *eras*, as well as different characters within each rung: clients, managers, designers, builders; design and communication tools, etc. For instance, in the fifteenth century at the construction of the Dome of Santa Maria Del Fiore Cathedral, Brunelleschi was the designer as well as the builder, and he himself directed the bricklayer. Brunelleschi designed through a physical model. He was known to keep his calculations and solutions a secret in order to keep the commission, forcing the builders to rely on him to accomplish the task. Five hundred years later, in the mid-twentieth century, the designer(s) would release a large number of drawings to the builder (a new player), without the risk of losing the commission: written contracts set out the rights and duties of each party involved.[7] Physical models and photomontages were extensively used as part of the process. Speech, texts, drawings and models were present, with different strengths, in both cases described above.

Moving forward 50 years in history, when the use of computation became detached from computing codes, from the mid-1990s onwards, the *new* computerized design process became highly efficient. Among the advantages of the newly created digital drawing technology, the two most prominent were: (1) to erase and redraw little bits of a drawing without the need to make up an entire sheet; (2) to copy, multiple times, a specific piece of design across the drawing. These

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[6] As mentioned in previous paragraphs, the "traditional architectural image" is not classified as Flusser's traditional image. The Flusser model is used as a lens to understand the object, not as static categories of classification.

[7] This is a topic itself. There is a book currently being written by Professor George Johnston, School of Architecture, Georgia Tech.

advances had a strong impact on the architectural industry: a reduced number of staff were now able to produce a great number of drawings in a much shorter time. The digital two-dimensional architectural image, the CAD image, belongs to the fifth rung: it is a technical image.

Despite the black screens populated by colored lines and shapes, the digital drawing technology, two-dimensional CAD, is still a simulation of a hand drawing. One needs to translate his thoughts into a two-dimensional geometric code of lines and shapes, line weights, shades and colors. Apart from the speed and reduced staff, the "vocabulary" and its "orthographic" rules remain the same, as well as the flow of information within the design process. The flow of the design process can be simplistically described as follows:

Actions and initial architectural images (traditional or technical) become a program.[8] *The program and actions (verbal communication) feed the design team; the design team produces further refined architectural images and texts; the refined images and texts undergo further actions; further actions adjust the program accordingly. The program and actions again feed the design team…* This continuous loop ends when a design is agreed upon or when the client is running out of time, whichever comes first. The number of loops until the project ends depends upon time, the complexity of the design, the ability of the design team and the ability of the management.

The so-called *digital shift* added new layers to this process. One new character, an instantaneous-simultaneous interaction, is changing the two-dimensional rationale behind the design process, as well as the information flow, poorly described above. Different actors can edit the *work in progress objects* (text or drawings) simultaneously. The unidimensional linearity of the process has shifted to a network-like progression, the history of any design process has become harder to be traced, and a much wider range of interpretations are now available. The design objects (texts and drawings) have acquired new dimensions: the so-called *revision*, the *still moment* from an ongoing process, is not as *still* as before. This interactiveness, added to the different levels of analog simulation, have clouded the lens that looks at the process.

Another feature of the simultaneous interaction is that one can easily access information previously placed in a source. The so-called virtual libraries embedded in the apparatus, a predetermined group of materials, textures, details of joints and transitions, furniture, etc. Generally, these libraries are open to its users to add new items at any time, making it an enormous source of data. Dealing with this *big data* is becoming a matter that is more sophisticated than the creation of new data, the creation of new knowledge. The new consciousness has become a matter of finding, filtering and combining the relevant data from the existing source; it is not as much a matter of producing new knowledge. One can argue that the same rationale has its analogy in the

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[8] Text that describes the client's requirements. It is the architect's starting point. It could be a single page or a multiple-volume document, depending on the complexity of the product desired. Generally, this document is constantly adjusted during the process.

twentieth-century analog libraries (the re-collection of pre-existing data and its further combination), yet two differences must be highlighted: (1) not everything could be instantly and freely added to a twentieth-century source of data. There was a screening – a selective process previously made by one person or a group of people, the role of the editors, a subject discussed by Flusser. The discussions between authors and editors is controversial, and in many cases it has an authoritarian character, but the majority of knowledge produced was submitted to further discussions and would, anyway, evolve, even if it were still susceptible to rejection. The author-editor relationship does not apply only to books in libraries, but also to a standardization of details or material samples or anything that needed to be reviewed and accepted by a more senior authority. (2) The way the information was displayed during the analog era allowed for a much wider range of interpretations. The simple gesture of touching and reading a written text, a printed image or a tridimensional object, the acknowledgement of the real tridimensionality of the *things,* gives a sense of freedom/empowerment to interpret in an adverse or even skewed path.

The recently created design tool Building Information Modeling (BIM systems) is an additional character in this problem, applied to the architectural environment. Cognitively distant from the two-dimensional representation, the BIM is not a simulation of a hand drawing, nor is it a simulation of a construction site. A virtual construction site exceeds the limitations of a two-dimensional representation. Any shape created in this virtual construction site can, potentially, be measured and built, considering the use of tridimensional printers and similar apparatuses. The mental process of understanding an object, breaking it down in plans, sections and elevations, is now placed within a computer algorithm to be sent straight to the *printer*. The representation of a helicoidal stair by a traditional two-dimensional method, for instance, would rely on descriptive geometry knowledge to produce accurate measurements as well as the gesture of drawing the lines to represent its steps, and the additional lines to represent the handrail, that would ultimately force the designer or draftsman to acknowledge that the handrail should be joined to the step, even though this *joint* would be developed later on. In a BIM-like environment, an equivalent stair is pre-stored in a library. Joints, details, and textures are pre-set. Every parameter can be manipulated and new ones can be added, but the latter is rarely the case. In an environment that relies on pre-set data, the creation of new or bespoke features are even more distant from the design process.

The second turning point in human civilization stated in Flusser's hypothesis might be occurring now. In the case of the design process, there is no longer a need to know descriptive geometry or two-dimensional representation in order to know how an object will be constructed or manufactured. Details, joints and finishes are either embedded within the "apparatus" or they are dimensions – impossible to be measured in a traditional architectural drawing – that will be sent to the printer, without further human thinking. Knowledge is being placed in a virtual model and, maybe, is freeing up mental room for new kinds of judgment, a reshaped critical thought.

The fifth rung proposed by Flusser, the Universe of Technical Images, had a tremendous impact on industry, economy and society: they were efficient technologies that sped up the processes, as well as laid off a big chunk of the workforce. It was an efficient simulation of the analog world but did not reshape *historical consciousness*. We might be witnessing the beginning of a *Sixth Rung.* As a reference to Vilém Flusser's writings, it might be called the Universe of Virtual-Interactive Media: non-existent (virtual) tools manipulated by multiple characters, generating multiple possible results. As well as the *text* that became detached from the page around the twelfth century, tools are becoming detached from real objects and the complementary relationship among the five rungs has ceased to exist: actions, objects, texts, and images (traditional and technical) are now combined, merged in this virtual environment, and our consciousness is undergoing a transformation due to this *innovative technology.*

Per Flusser's quote: "Two possibilities to face the world, one is through image and other is through linear writing" (Flusser, 2013). We are facing a third possibility, the non-existing (virtual) interaction.

The *flusserian* logic sets an interlacement between the fourth and fifth rungs: technical images and texts may restrain the interpretation of one another. At the sixth rung the amount of intellectual technologies is much greater and its interlacement more complex. For instance the *grasping* property of the second rung, not accounted as a vehicle of consciousness on Flusser's rationale, seemed to be a highly important feature to carry consciousness at the sixth rung: tools acquired virtual functionalities detached from real objects; its use is an interpretation itself as well as a vehicle of consciousness, not necessarily the object produced by the tool. Interestingly the iconographic *vocabulary* placed at the computer screen and used by the virtual tools can be understood as a return to a pictoric writing, a neo-ideographic alphabet. In an architectural design process the design tool - BIM model - besides allowing indefinite ways of use, one of the big challenges is to grasp the X-*dimensionality* of its virtual existence. The *traditional* bi-dimensional representation is a simplifier tool that extinguishes the parallaxes of a tridimensional observation as well as provides its true dimensions, any complementary information is carried by additional objects such as texts, schedules, physical and digital models, etc. The complementary relation among these objects keeps their independence: they address each other but don't rely on each others' existence in order to operate. On the BIM model, a tridimensional virtual object, the complementary information is embedded within the system and depends on the other's existence in order to fully operate. It is not possible yet to interpret all these layers of information by only observing these tridimensional virtual images bi-dimensionally projected on a computer screen or bi-dimensionally printed on a piece of paper. Access to hidden information is necessary to enable interpretations that are equivalent to interpretations of texts, architectural drawings or even the interpretation of an interlaced system of texts and technical images. At the sixth rung relevant information or data is not accessible right away, if accessible at all, this might compromise any further interpretation. The consciousness of the design process or its historical consciousness - an evolving loop of conflicting interpretations - is being replaced by a web of interdependent connections that do not necessarily move forwards, and do not necessarily return to a cyclical pattern. This virtual web of connections opens up possibilities that overcome the linearity of historical consciousness. An effect analogous to the overcoming of mythical thought by language. It might be the beginning of a new consciousness where any missing piece or turbulence at any one or more connections might take the system to undesired or unprecedented paths. We are experiencing an early stage of the sixth rung, therefore any attempt to describe or acknowledge its effects on society is premature and ultimately inaccurate, however an admittedly incomplete definition must be made in order to open a void for further critics and keep the *flow* of historical consciousness, at least while it still remains in its actual shape:

The Sixth Rung is a level of interdependent information web: the invention and evolution of non-existent/virtual tools and simultaneous interactivity of its unities. A zone where linear thinking is replaced by multi possible dimensions.

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Clarifying BIM: Two erroneous propositions

Keywords

Building Information Modeling, Digital Design, Digital Fabrication, Facility Management.

Abstract

Building Information Modeling - BIM is advertised as the ultimate technology for designing in Architecture. In practice however, the marketing claims are still unsubstantiated and have resulted in unrealistic expectations about its functionalities and effectiveness. There is a divergence between claims/expectations and practice. Scientific literature has failed to situate BIM within the functionalities of digital design and demonstrate its realistic effectiveness. In this paper, we identified two erroneous propositions that induced this overestimation of the applicability and effectiveness of BIM.

1. Introduction

Building Information Modeling (BIM) is a process of constructing an information-rich virtual simulation of a building, including its structure, infra-structure, components, and finishes - all the nuts and bolts. Due to its level of detail and concordance with physical reality, this tri-dimensional digital model can, theoretically, provide accurate and real-time data useful for cost control and scheduling as well as produce graphic outputs, drawings and details, as needed and in scales and formats appropriate to their use.[1] Although literature suggests that BIM complies with a wide range of contexts and modalities, our interpretation of the same sources does not agree with such optimistic point of view (Eastman 2011, Holden 2012, Kensek 2014). Our research reveals that the main purpose of Building Information Modeling is to enhance the management of design and construction processes.

BIM has been used as a generic definition for any digital technology that involves 3D visualization. This gives opportunity to terminological misuses, inducing the assumption that BIM platforms can comply with a variety of functions and uses that radically differ from its original management purpose. The distinct functions most often associated with BIM platforms are Digital Fabrication and Facility Management. The digital tools required to perform management of design and construction, digital fabrication, and facility management are highly differentiated. Scientific literature has only indicated efficiencies hypothetically achievable in the first of these functions while users are often motivated by positive assumptions supposedly applied to the other two. The conflation of digital design functions turns the effectiveness of

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[1] One of the big features of BIM software is the ability to embed data in objects modeled inside the software. The nature of this data can vary: spatial dimensions or areas, amount of fixings (doors, windows) or material specification. This data can either be produced by the software or input into the software during the process. The software also allows automation to some extent, i.e. to highlight design errors. The data and automation grow larger and more complex as the project evolves.

BIM into a magic word for clients and/or owners. But it also gives rise to reasonable doubts among designers. This article clarifies two erroneous propositions about BIM.

2. Brief Historical Overview of BIM

The idea of computer-aided architectural design began in the early days of computation. Since the early 1960's several attempts for conceptual frameworks and interfaces for 'computational' design have been made, but the first successful project was the Building Description System proposed in 1975 by Charles Eastman in his paper "The Use of Computers Instead of Drawings in Building Design" (Eastman 1975). Eastman highlighted weaknesses of handmade architectural drawings and suggested how they could be overcome using computers. He proposed three-dimensional shapes created by computers, which could generate orthographic views by cutting "…sections through the shape to derive planes, sections, isometrics or perspectives from the same description of element" (Eastman 1975). This process could eliminate inconsistencies across a project caused by mistakes/errors in drawings made by hand. In addition, those drawings could be generated on demand, following consultants' or contractors' needs. Reports for cost estimation or any type of quantitative analysis could be easily generated as per Eastman 1975. These ideas have influenced many research projects throughout the world, but Eastman's digital lab established at Georgia Tech is still today the benchmark for design and construction using digital technologies.

The so-called Computer Aided Design (CAD) only became popular from 1990s onwards using software developed to mimic two-dimensional hand-drawings. The drawings were produced following the same rationale as descriptive geometry used by traditional hand-drawing: plans, sections and facades drawn on digital boards, later by mouse and visible on computer screens. This *new* computerized design process was highly *efficient* when compared to traditional methods: A reduced staff could now produce the same amount of drawings in a much shorter period of time than had been the case a few years prior.

In his 1975 paper, Eastman had hypothesized that additional capabilities would be realizable by the generation of two dimensional drawings from tri-dimensional models. These included the reduction of drawing errors and inconsistencies as well as the ability to make accurate quantity take-offs for cost control and estimating purposes (Eastman 1975). By the end of 1990s several platforms such as Autocad, Micro Station and Micro GDS were already testing how to embed data such as material specifications and cost factors into the drawing; but the input, revision, and retrieval of that information could take so much effort that older methods of writing the data in separate files was still more efficient. The concept of file sharing, i.e. a single file being used simultaneously by members of multi-disciplinary design teams, was a later development not originally anticipated in Eastman's 1975 paper.

By the early 2000s, the three-dimensional aspect of BIM was consistently incorporated into available software. In addition to the possibility of generating two-dimensional drawings from a three-dimensional model, attempts of automation were already being implemented. The 3D models could potentially identify building regulations and information clashes among the design disciplines (consultants) while information about materials, finishes and equipment could be embedded into the 3D models allowing some level of quantity take-offs as well as data retrieval. Taken together, these capabilities showed enormous promise to improve the management and efficiency of the design process as Eastman had first suggested.

3. The Two Erroneous Propositions

In addition to the primary focus of Eastman's 1975 paper, BIM is frequently adopted by key authors and designers (Eastman 2011, Holden 2012, Kensek 2014) as a generic term that refers to two other functions of the design and construction cycle: digital fabrication and facility management. The failure to make these distinctions clear conflates claims and expectations. The capabilities demonstrable in one of these domains of digital design (Digital Fabrication, Facility Management, and Design Management) are not per se achievable in all three.

3.1 Erroneous Proposition One: *Digital Fabrication is a Function of BIM platforms.*

It is difficult to define whether digital fabrication unfolded from Chuck Eastman's original proposal, or if it was researched and achieved elsewhere and later incorporated by Eastman's digital lab at Georgia Tech. Nevertheless, Digital Fabrication is an independent process in which a building part is designed through and fabricated from digital media, a tridimensional model. However, the software used for Digital Fabrication is not ideal for the BIM process of data input and retrieval. The 'digital fabrication model' needs to be imported to a BIM software in order to provide ideal design management. There are already initial attempts to incorporate Digital Fabrication features inside BIM software but at present they have not yet succeeded.

Although Eastman did not acknowledge the possibility of Digital Fabrication in his 1975 paper, it was the first function of Digital Design that was widely reported by media. The Guggenheim Museum Bilbao designed by Frank Gehry (1992-97) was the first project developed through so-called Digital Fabrication widely reported (Chang 2015). The gestural shapes that defined the museum's “envelope” were built with the support of *Catia* - a software used to develop the French Mirage aircraft. (Chang 2015)

During the twenty years that passed following construction of the Guggenheim Museum in Bilbao many software packages were developed specifically for the AEC industry to handle BIM processes and 3D modeling. Around the year 2000, BIM platforms became accessible to architects, engineers and contractors. Practices such as Zaha Hadid, Morphosis, UNStudio, Foster and Partners, and OMA, to name a few, began using the software tools frequently in order to develop and construct buildings with gestural shapes. These buildings and their strong exposition in the media contributed for the Digital Fabrication to remain the most popular function of the Digital Design.

Digital Fabrication is an independent process in which a building part is designed through and fabricated from digital media. Digital fabrication software does not include features that support BIM processes. Yet many reference books about BIM include chapters solely about Digital Fabrication. Chapter 7 of Chuck Eastman’s BIM handbook (Eastman 2011) is dedicated specifically to Fabricators. It discusses automated manufacturing, prefabrication and assembly. The only aspect of fabrication specifically linked to project coordination is the benefit of paperless processes when correlated to the cost of the detailing as compared with traditional processes. The chapter also underlines the ability to produce 3D visualizations as a powerful advertisement tool, a feature to assist in obtaining work; however, 3D visualization is not a feature associated with BIM or DigiFab only. Any technology that involves 3D modeling can benefit from it.

3D visualization does not necessarily need to be digital. A digital 3D model is more mobile but not radically different than buildings drawn in the perspective space invented in the Renaissance (Yaneva & Latour 2008). The cost and time consumed to produce any graphic representation able to illustrate finishes and details of a building in all its minuteness is very high, regardless of whether it is digital or handmade. The digital version can provide a dynamic or "fly-through" visualization entailing additional cost and production time tied to technical requirements. Nevertheless, both versions serve illustrative purposes solely.

Chapter 7 of the BIM Handbook (Eastman 2011) becomes even more confusing with the inclusion of a table called "BIM software for subcontractors and fabricators." This table groups software of different functionalities under the same umbrella (so-called BIM software), even though the content makes clear distinctions between software for fabrication and software for coordination.

Chapter 2 of the book Building Information Modeling (Kensek 2014) discusses the functionalities of digital design, considering Digital Fabrication and Facility Management as distinct competences of BIM. The acronym BIM is considered by Kensek a generalization for a variety of software used for Digital Fabrication and Facility Management by stakeholders.

Chapter 16 of the book BIM: in current and future practice (Kensek; Noble 2014) mentions BIM in the title; however, it does not discuss the coordination aspects of digital design.[2] The chapter

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[2] Chapter authored by Christopher Beorkrem, UNC Charlotte School of Architecture.

discusses software and modeling constraints imposed by material properties and the standard dimensions available in the market. It does mention Revit, a BIM software, referring to it as a holistic modeler while dismissing the fact that Revit does not support fabrication. The "holistic digital model" ultimately will need to be exported from Revit and imported into an appropriate software for Computer Aided Manufacturing (CAM) in order to be fabricated. The interoperability between the software is ignored.

Part of the scientific literature is failing to distinguish functionalities within the realm of digital design (Eastman 2011, Holden 2012, Kensek 2014). It also assumes that digital processes are changing the modes of existence in general: communicating, commuting, shopping, housing, living (Jeong 2009, Steel 2010, Eastman 2011, Holden 2012, Case 2014, Ghaffarianhoseini 2016). In the Architecture Engineering and Construction industry, some of these misplaced arguments are motivating clients and owners to require BIM as a mandatory platform. One proponent extols BIM as "the key technology leveraging change and innovation in the construction industry that is offering the opportunity to totally reinvent contemporary construction design and delivery practice for future development." (Ghaffarianhoseini 2016).

There are many books[3] that discuss how Digital Design is reshaping the AEC industry, in terms of both the practice of architecture and the digital generation of architectural form. This debate is largely based upon the following two premises: 1) the enhanced capability to investigate materials and construction methods and logistics enabled by the Digital Fabrication processes in

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[3] such as Building (in) the Future (Deamer 2010); Emerging Models of Architectural Practice USA (Kedan 2010); Integration Innovation in Architecture (Aksamija 2016); Digital Workflow in Architecture (Marble 2012) to name a few.

the realization of complex gestural building forms and assemblies; and 2) the new potentials of mass customization as compared to mass production.[4]

These two arguments do not address the coordination function of digital design which is its dominant role of the industry rather they over emphasize the importance of BIM or digi-fab. According to Kedan (2010) the majority of architectural practices consistently exploring digital fabrication are located either in US or UK, and "much of the manufacturing they rely on as well as the majority of their clients are located in expanding economies of Asia" (Kedan 2010). Nevertheless, digi-fab projects are typically developed within very exclusive contexts and receive enormous exposure in the media despite representing only a small portion of the AEC industry.

3.2 Erroneous Proposition Two: *Facility Management Is a Function of BIM Platforms.*

Facility management is a practice that coordinates maintenance and operational strategies of a building as well as the management of human resources and information technology. Although it is reasonable to assume that buildings of any kind have required some level of maintenance and operational management throughout the history of architecture, there is nonetheless an extensive debate in contemporary literature about the origins of Facility Management (FM) as a discipline (Nor 2014).

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[4] This concept is discussed in depth by Mario Carpo in his book *The Alphabet and the Algorithm*.

History provides us with many examples of FM: healthcare facilities from the 10th century already required high-level operational and maintenance strategies; so did the ‘Grand Hotel’ from the late nineteenth century with its nearly one thousand sleeping rooms, dining rooms and ballrooms. The 24-hour-service luxury hotels from the mid-20th century required constant maintenance of their enormous amounts of machinery, in addition to the complexity of their operational logistics (Mindlin 1962). Operational and maintenance logistics were coordinated through spreadsheets and schedules produced with pen and paper. In the late twentieth century handmade spreadsheets were replaced by software specifically designed for facility management.

As buildings or facilities become more complex, the management of their functions needs to be more strategic and tactical (Nor 2014). By their very nature, these buildings or facilities require regular renovations and expansions. Architects responsible for the design were also increasingly responsible for providing the necessary information to enable this Facility Management through an accurate survey of the building as it was actually constructed – the “as-built” drawings.

Literature regularly describes Facility Management as a sub-topic of digital design and suggests that it is a feature of BIM software (Eastman 2011, Holden 2012, Kensek 2014, Aksamija 2016). Eastman’s *BIM Handbook* argues that BIM’s contribution to facility managers is to optimize management and maintenance providing all relevant as-built data and equipment information. The book *Integrating Innovation in Architecture* (Aksamija 2016) claims that BIM encompasses the entire life cycle of a building, including Facility Management after completion. It suggests that BIM offers a new method for management of buildings that could ultimately skip the phase of as-built data collection. So BIM is seen as a provider of an unified database of all building components, allowing all types of information (including manuals and specifications) to be stored and to become retrievable whenever necessary. In short, the digital tool would be able to track all building uses, equipment location and perform the necessary calculations to support FM. The book *Building Information Modeling (*Kensek 2014) argues that strategic planning, management and operations are among the applications of BIM. Unlike the other authors, however, Kensek identifies the additional cost implied by the application of BIM to the task of facility management. Her book suggests that architects, owners and contractors should discuss their responsibilities regarding inputting data and updating the BIM model, clarifying this responsibility in the contracts or even considering hiring a third party for this role. Under this perspective BIM would no longer be a mere Building Information Model. Once the design is concluded, the entire database and automations of this final version should contain enough information to become a Facility Management model.

The Contradiction - The BIM model produced by the designer will always need to be adjusted in order to accommodate the construction methods of the contractor hired. Different clients or owners will require different kinds of data for Facility Management and so adjustments will often be necessary. But some of this data may not be relevant for the designer and/or constructor. Information needed for Facility Management will be spread across at least two models: the design model and the construction model However, neither of these are yet the so called as-built. The construction of an 'as built/FM model' requires a survey of the building after its construction is completed. This exercise is an additional (and high) cost.

Another assumption among clients and owners is that the BIM/Facility Management model could replace Facility Management (FM) software due to the amount of data it contains and the automation it presumably allows. However, the relevant data must be retrieved from the BIM model, i.e. exported, and then imported into the Facility Management software. This export / import process and the interoperability among these platforms is an important topic in the BIM technical literature.

Nevertheless, in the literature there are frequent claims (Eastman 2011) that the final BIM model will respond to the owner's needs if the project is developed in a highly integrated way, with all the stakeholders – owners, designers, contractors and sub-contractors - involved from the early stages of the process. Such claims are embedded in two fallacies: (1) that the model is continuously updated during construction to reflect changes in the field; and (2) that highly collaborative projects are the majority of the AEC industry. These ideas do not match the facts, since in the most cases the constructor is hired through a bidding process only after the design is concluded. Designers convey the BIM model to the hired constructor and subcontractors. Not surprisingly this model can undergo significant changes, especially in consideration of the additional intellectual ownership issues and contractual liabilities. Usually the information necessary for FM is further apart since some of the stakeholders who own the information have probably never met and the responsibility of collecting and organizing the FM data becomes cloudy. This can mean not only additional costs to contracts but often a new contractual agreement altogether. Rather than being a seamless extension of BIM functionality, Facility Management turns out to be an independent process that, potentially, uses the data embedded in a specially-commissioned as-built BIM model.

Final Remarks

Building Information Modeling is a popular topic in academic research and a technological trend in the AEC industry. However, there is a divergence between claims/expectations and practice. BIM is perceived as the holy grail of the AEC industry with the potential to accelerate the design process, increase the efficiency of the construction process, and therefore to decrease cost. In practice however, these claims about BIM are still unsubstantiated, and have resulted in unrealistic expectations among clients, owners and designers about its effectiveness.

It is not surprising that software developers overestimate the benefits of their products in order to increase sales. Marketing strategies based on hypothetical achievements are not unusual either. The conflation of functionalities misattributed to a single-multifunctional tool has contributed to a lack of clarity in distinguishing between hypothetical and realistic achievements of the differentiated functionalities of distinct digital tools.

Recognizing the two fallacious assumptions presented by this paper is essential for progress in BIM technology. We believe that it is critical to educate clients and owners regarding the specific functions of digital design and the realistic risks and benefits of the technology in its present stage of development. Design is a social process that involves participants of different interests. Social processes demand communication, and the different interests of the participants demand different modes of communication. Relying, therefore, on a single communications platform, such as BIM software, especially when this platform imposes strong legal and commercial constraints, will ultimately hinder the whole process. We believe that researchers and designers should conceive a different strategy, inside or outside the digital environment, to support the existing BIM software but one able to overcome the legal and commercial constraints of software industry.

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Assessing BIM Maturity in the context of Architectural Practice: An Ethnographic Analysis

Marcel Cadaval Pereira - PhD Candidate at COPPE/ Federal University of Rio de Janeiro;
Address: COPPE/UFRJ - Engenharia de Produção - Sala F-103. Caixa Postal: 68507, CEP: 21941-972
Rio de Janeiro, RJ, Brasil. **Email:** marcelcpereira@gmail.com **(Corresponding Author)**

Roberto Bartholo - Professor at Federal University of Rio de Janeiro School of Engineering;
Address: COPPE/UFRJ - Engenharia de Produção - Sala F-103. Caixa Postal: 68507 CEP: 21941-972
Rio de Janeiro, RJ, Brasil. **Email:** bartholo.roberto@gmail.com

Francisco Moura Duarte - Professor at Federal University of Rio de Janeiro School of Engineering;
Address: COPPE/UFRJ - Engenharia de Produção - Sala F-103. Caixa Postal: 68507 CEP: 21941-972
Rio de Janeiro, RJ, Brasil. **Email:** fjcmduarte@gmail.com

George Johnston - Professor at Georgia Tech School of Architecture;
Address: Georgia Tech School of Architecture **-** 245, 4th Street NW, Suite 351, Atlanta, GA, US.
Email: george.johnston@design.gatech.edu

Assessing BIM Maturity in the context of Architectural Practice: An Ethnographic Analysis

Keywords:

Building Information Modeling, Facility Management, BIM maturity, BIM risks and benefits, BIM ethnographic study.

Abstract

Building Information Modeling (BIM) is perceived as the holy grail of the Architecture Engineering and Construction industry (AEC) that allows innovative construction methods with the potential to increase the efficiency of the delivery cycle of design and construction. In practice however, its benefits remain fairly unclear. Due to the confidentiality nature of the industry, the comprehensive assessment of BIM usage is scarce. The BIM empirical studies in the literature are either interpretations of historical data - questionnaires performed after the project was concluded - or software testing performed outside the office's environment, ignoring the day-to-day conflicts and struggles. Aiming to initiate filling this void, this paper describes an ethnographical study conducted inside an architecture practice. The transcriptions and interpretations presented in this work are focused on the effectiveness of BIM and its relation with the level of implementation and proficiency of the BIM software, that is BIM maturity.

INTRODUCTION

Building Information Modeling (BIM) is a process of constructing an information-rich virtual simulation of a building, including its structure, infrastructure, components, and finishes - all the nuts and bolts. Due to its level of detail and concordance with physical reality, this tri-dimensional digital model can, theoretically, provide accurate and real-time data useful for cost control and scheduling as well as produce graphic outputs, drawings and details, as needed and in scales and formats appropriate to their use.[1] However the benefits of BIM remain fairly unclear. Practice shows that the transition from two-dimensional CAD to BIM has been demonstrating a "weakest link" phenomenon. If one single member of a design team cannot adequately comport with the dictates of the common platform, then the full collaborative potential of BIM is not realizable. That is, the level of BIM implementation and proficiency across the design team must be precisely same. Literature suggests that a project becomes more efficient the higher the level of BIM implementation the company can achieve. However, the models for measuring BIM implementation are still highly theoretical, they lack adequate empirical evidence of application. Aiming to initiate filling this void, this paper presents an ethnographic observation performed inside an architectural practice. The interpretations of this study are focused on the effectiveness of BIM in practice and its relation with the level of implementation and proficiency of the BIM software, that is BIM maturity. This text is therefore divided in two segments: The first segment is a brief literature assessment of scientific texts and governmental documents related to BIM maturity. The second segment presents the methodology, transcripts and interpretations of the field research: the ethnographic observations of the work performed inside an architectural practice. The findings of the literature assessment and the field research are synthesized in the final remarks.

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[1] One of the big features of BIM software is the ability to embed data in objects modeled inside the software. The nature of this data can vary: spatial dimensions or areas, amount of fixings (doors, windows) or material specification. This data can either be produced by the software or input into the software during the process. The software also allows automation to some extent, i.e., to highlight design errors. The data and automation grow larger and more complex as the project evolves.

1 Literature Assessment

In the scientific literature, much has been discussed about the level of BIM implementation focused on measuring the ability to operate within BIM platforms and exchange information among the stakeholders (Succar et al 2012, Chen 2014, Copping et al 2016). According to Copping et al. (2016) BIM levels are measured by theoretical assessment models that are usually based on a 5-level scale (1-5) suggested by Succar et al. (2012). BIM maturity, or the BIM level, is increasingly becoming a qualifying condition for public bidding and a requirement imposed by clients when selecting among competing architectural firms.

According to Chen (2016) et al., BIM maturity is measured by four dimensions; 1) hardware infrastructure, 2) software infrastructure, 3) human proficiency on the platform (software and hardware) and 4) management and delivery. These metrics assume the latest BIM software installed on powerful computers operated by trained personnel. The efficacy of information management-delivery is an evaluation of team efficiency using the combination of the other three dimensions described. Each of these dimensions is scored within different areas such as: workflow, senior leadership, training level, quality control, standardization, etc.

As reported by Copping et al (2016) there are 16 assessment models available to date. The scoring system and measured areas vary for each model while the dimensions measured -- computer power, appropriate software, software proficiency and personal efficiency -- are the same for all the models. The majority of the models involve self-appraisals based on a questionnaire, usually in "multiple-choice" format. According to Copping et al (2016) the most reliable assessment model was developed by Building Research Establishment (BRE),[2] a British private institution that provides the BRE-BIM-level 2-certification (2015), among other certifications for the AEC industry. In the British BRE certification system a third-party is required to complete the assessment, which incurs a fee while the other models are self-assessments freely available to the wider industry. Some practices claim that the models only focus in one area and not on the entire project. In 2014 for instance, Arup developed its own assessment model that supposedly accounts for a wider number of variables.

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[2] Building Research Establishment (BRE) is a center of building science in the United Kingdom, a former UK government national laboratory that was privatized in 1997. BRE provides research, advice, training, testing, certification and standards for both public and private sector organizations in the UK and abroad.

Most theoretical assessment models measure BIM maturity based on the 5-level-scale (1 to 5) suggested by Succar et al (2012). The maturity scale suggested by National Building Specifications (NBS), the British organization that sets standards for the AEC industry in UK, is the model used by BRE for its BIM-levels Certification. The NBS maturity levels run from 0 to 3, differently from the 5 levels suggested by Succar et al (2012). The scores earned on the assessment determine the company's BIM level. However, the BRE appraisal questionnaire is confidential. In theory, even the assessed practice does not have access to it. An appraiser is sent to the design practice being assessed in order to observe, ask questions, take notes and fill out the BRE questionnaire. Throughout the appraisal process, the BRE appraiser may make recommendations in order to improve the company's scores in a later reassessment. Although the BRE procedure is a practical application of a maturity model, it remains a conundrum due to its questionable claims of confidentiality.

Additionally, BIM levels in theory measure the proficiency of the design and construction teams in terms of the integration and interoperability among all the different stakeholders and design disciplines operating within the BIM platform. Accordingly, any BIM certification granted to a single company can be misleading because BIM maturity relates to the BIM level of the team as a whole. It cannot guarantee that any processes performed by a single participating company will reach the BIM level of the certification granted. Both models tackle BIM-software proficiency among members of a team. They do not consider, however, "day to day" complications due to software imperfections or the obstacles commonly encountered when variable levels of software proficiency are present within the same team. Variations are also possible in terms of the different ways software may be implemented by different users or teams with regard to established BIM standards. Considering that in the AEC industry the members of a design team have different kinds of expertise by nature, it is very likely that the BIM software will be used within a spectrum of different approaches, at least at the initial stages of the design or until design standards are agreed. Maturity models are conceptual recommendations, according to Chen et al (2016), most studies were limited to the theoretical proposal, and there is limited empirical research to test the reliability and validity of the models and frameworks.

According to Copping et al (2016), most studies have focused on introducing and promoting new models, rather than implementing them in the AEC industry. In addition, there is still a shortage of literature which examines *assessment models* in practice. Interestingly the maturing assessment model proposed by Copping et al (2016) was actually developed by Arup in order to measure Arup's own BIM maturity.[3]

Smits et al. (2016) suggests that the impact of BIM maturity on project performance is limited and cautions against over-optimistic appraisals of BIM. Smits et al (2016) presents the results of a large-scale survey research performed among 890 Dutch AECO professionals. The survey tried to understand and measure the relation among time, cost and quality performance. The results showed that the effect of BIM maturity on cost and time performance was surprisingly low.

According to Arayici et al (2018), for projects focused on environmental performance and sustainable design, the full potential of BIM has not yet been achieved because of a lack of integration that prevents collaborative relationships amongst team members throughout the project lifecycle. This is due to lack of clear guidance or the low level of BIM utilization. BIM's use in practice has mainly been at Level 1 and has only rarely attained Level 2.[4]

Despite the lack of empirical evaluations of BIM in practical application, some countries have systematically mandated the use of BIM for centrally procured public projects. In 2011 the UK Government Construction Strategy demanded BIM level 1 as requirement for participation on public bids (Government Construction Strategy 2011-2015). The UK Construction strategy 2016-20 requires BIM level 2 (Government Construction Strategy 2016-2020).

To this date, UK, Scandinavia and Australia are the only places where BIM is mandatory in public bids. However, it is fair to say that in Scandinavia and Australia the levels of BIM adoption are varied and disjointed. There is no consistent approach to the measurement or level of maturity (López 2016).

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[3] Arup is a British Design and engineering company founded in 1946, holding branches in 35 countries to this date.

[4] Level 1 BIM - Comprises a mixture of 3D CAD for concept work, and 2D for drafting of statutory approval documentation and Production Information. Electronic sharing of data is carried out from a common data environment (CDE), often managed by the contractor. Models are not shared between project team members. Level 2 BIM - All parties use their own 3D CAD models, but not necessarily working on a single, shared model. The collaboration comes in the form of how the information is exchanged between different parties. Design information is shared through a common file format, which enables any organization to be able to combine that data with their own in order to make a federated BIM model, and to carry out interrogative checks on it.

The other countries that claim to use BIM still have published guideline recommendations and provisions for full implementation in the future. Spain for example first published in 2015 its vision for the adoption of BIM level 2 by 2018. The *Recommendation Guide* published in 2016 and updated in 2017, however, does not mention a specific BIM level and remains the latest official document released by Spain planning authorities. Then in 2017, adding further confusion, Spanish planning authorities announced that BIM level 1 would be mandatory starting in 2018. The same rationale to "push forward" applies as well in other developed countries such as France, Belgium, and Germany.

Turk (2016) questioned the slow dissemination of BIM platforms. According to his paper if BIM is as good as advertised, why should its use in private investments be mandated by law? There was no government action to force businesses to start using the web, mobile phones, and management information systems. Some businesses did and succeeded; others did not, failed and lost in a competitive market. Industry is rational; it uses what is useful.

Interestingly numerous papers use social theories of technology diffusion in order to explain the lag-time in full BIM implementation. A paper written by two professors of the Northumbria University in UK aims to measure the current level of implementation of 4D BIM in UK. 4D BIM implies in adding scheduling data to components of the model enabling the generation of program/ timescale information. Linking in cost data in order to support cost planning and generate estimates is known as 5D BIM, whilst the inclusion of information to support facilities management and operation is called 6D BIM. 4D, 5D and 6D are the newest trend in the BIM theoretical realm. Gledson et al (2017) used the *Innovation diffusion theory* proposed by Everett Rogers to analyze a questionnaire-survey that was completed by 97 design practices. As an outcome, the work suggests that future research should include qualitative investigations and consequences of 4D BIM adoption. These suggestions reveal that the 4D BIM is still in an embryonic phase of implementation in UK.[5]

Rogers' theory is frequently referenced by papers about BIM as an explanation for the slow progress of BIM diffusion; however, its use is questionable considering that 4D BIM is a digital, not an analog, technology. Rogers' theory attempts to explain the rate at which innovation spreads; however, at the

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[5] Apparently UK still has the most advanced implementation of BIM. The vision for the UK Construction Strategy 2025 is currently requiring 4D BIM.

time *Innovation Diffusion Theory* was first published in 1962, the speed of technological innovation was much slower than today, especially when compared with the frequency of software releases. Besides, at that time innovations would take much longer to spread across society due to distribution logistics and cost. Today, a new software, or its new version, can reach a large market of users within hours, in some cases with no cost. Society is facing a new condition where digital innovations are happening at such speed that it does not allow enough time for a new technology to be learned, used and adjusted according practice. The intercession of the internet has radically accelerated the rate of technological diffusion.

The measurement of BIM implementation and the assessment of BIM maturity levels are still highly theoretical at this juncture. They lack adequate empirical evidence of BIM applications and remain controversial in regard to BIM certification and its adoption as a mandatory platform. Generic claims about BIM innovativeness and unverified promises of lower costs and shorter construction time are among possible motivations for planning authorities to dictate BIM adoption for public sector projects. Efforts to assess BIM proficiency, as well as the rhetoric of technological innovation, are among the arguments inducing clients and owners to demand specific levels of BIM for their projects despite questions about the validity of the assessments and uncertainty about what they actually mean.

In the next segment, we will present field observations that were immersed in a setting where every designer and consultant used the BIM software (Revit) to its fullest. This setting allowed the observations to register and assess several design decisions by different designers made over Revit's interface. The field observations also tackled the extent of the modeling in order to meet the requirements of clients and contractors, as well as the extent of automation and withdrawal of data that is realistically possible, in other words this paper verified the efficacy of the concept of BIM maturity.

2 Ethnographic Study Performed in 2017 - The SLinUS case.

In this last segment, we will present a case study that was conducted with the aim to assess the efficiency of BIM process when performed within a setting of high maturity level. The findings were then compared with our interpretations of the literature review. Due to the logistics of our research as well as the liability and confidentiality nature of the participant architectural practice, the ethnographic observations were performed by one of the authors only. However, the conclusions were discussed among the group. The text is written in first person in order to comply with the writing standards of traditional ethnographic descriptions as well as to avoid creating confusing passive sentences.

2.1 Object of study, the architectural practice

During a period of 8 months - from March to October 2017 - I observed the work performed inside an architecture firm located in United States, specialized in senior-living projects[6], which I will refer to as SLinUS[7] (Senior Living in US). At the time of the research the firm had 60 staff members of which 45 were architects - managers and/or designers. The firm occupied one floor of an office-building. Its interior was laid-out in an open-plan with six working-islands, each accommodating between five to nine individual workstations. The perimeter of the floor was occupied by meeting rooms, owners and senior-staff' offices. The work-load was organized as follows: Project managers were responsible for several projects simultaneously, and each architect of their team was assigned to one or two of these projects, depending on the architects' experience and project' schedules. The sub-consultants were external parties and the communication was handled through email or phone calls. Theoretically the project manager and the architects responsible for her/his projects would sit in the same working-island. In practice, however, this didn't happen. The architects often moved from project to project depending on individual expertise and project time-schedules. Very often project managers and architects could be seen walking across the office searching for their team-partners.

Every project of the company was being developed in Revit. The software was installed in every computer assigned for design work and used by every architect-designer of the company. Every external consultant contracted by the company had a similar level of BIM proficiency. All project files were shared among the designers and consultants through a cloud based platform provided by Autodesk. BIM was fully implemented. Among the staff there was one architect entirely dedicated in coordinating BIM across the company, the BIM manager. He was responsible in guaranteeing the smooth functioning of Revit. According to the BIM maturity models discussed in the literature

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[6] The so-called senior-living in US is a private development aiming the senior population. The complex includes facilities designed for elderly population such as specific amenities and medical care rooms. Its price is below the market however when the occupant dies the unit must be sold back to the original owner for a previously agreed price.

[7] In order to meet the requirements of COPPE/UFRJ Institutional Review Board, the name of the company as well as the names of the people who participate on the research were kept in confidentiality by the authors.

assessment, this company could score as high as level 3 on the NBS maturity scale, or BIM level 5 on the scale proposed by Succar et all, depending on the project assessed.

2.2 Methodology

The ideal circumstance for an ethnographic observation of a design process is to track the entire design process of one building, from beginning to end, registering the meanderings and procedures of every design stage. Due to timing constraints however, this scenario was unrealistic. The design and construction of a building takes on average five years, without considering the usual interruptions for legal approvals, budgeting adjustments among many other bureaucratic procedures related to the AEC industry. In order to keep the schedule of the research I had to accomplish the field research in roughly 10 months. Following a single project during 10 months would restrict the observation of Revit functionality to very few stages of the design process with the risk of compromising the accuracy of the research. In conversations with the firm prior to my starting day it was agreed that I could observe projects in different stages of evolution and development. This was the only strategy that could allow me to comprise as many stages of the design process as possible to provide the best description of Revit functioning.

I was initially assigned to track down the work performed by seven architects that were sitting in the same working island. Not coincidentally, the projects developed by these architects were in different design stages. Projects developed simultaneously within the same company will very rarely be in the same design stage. Assigning me to a working-island seemed to be the most rational decision in order to facilitate my observations. I was also introduced to the BIM manager, he was supposed to answer my questions related to the functioning of Revit but not necessarily to be part of the observations. It took me around a month to understand the office's routine and to identify among this group of people who was really willing to spend time with interviews and occasional conversations. I was offered a vacant working station beside the BIM manager to use during the period of my observations. This desk was located right across the office from the island where "my" group was sitting. The distance from my team turned out to be very convenient. It forced me to constantly walk across the office and induce situations for architects beyond my group to ask me to participate in the research. Only two out of the seven architects initially assigned were open to letting me observe their work; however, my trips around the office allowed the inclusion of three additional architects, beside the participation of the

BIM manager, which became pivotal as the research evolved. I have tracked the work performed by five architects and the BIM manager. The projects and the design stages of each architects are described below:

Architect A- Convent renovation, Planning permit.

Architect B- Senior living, Design development

Architect C- Facade retrofit, Planning permit/ Senior living complex, design development

Architect D- Senior living renovation, schematic design/ Canopy of a building entrance, construction drawings

Architect E- senior living renovation, planning permit.

Beside the work performed by the five architects, I had two additional sources of observation: 1) regular visits the BIM manager received at his work-station from different architects looking for specific BIM consultations; and 2) meetings the BIM manager hosted every other week to discuss issues concerning BIM. The regular consultations would usually regard matters related to specific projects. The so-called BIM meetings discussed topics such as BIM standards, procedures, strategies for acquiring new versions of Revit, etc. The quorum of these meetings never exceeded eight people. The five architects already participating in my research were regulars, and two or three additional participants would attend occasionally only to clarify matters related to their own projects. These meetings and the BIM consultations were always followed by a very long and passionate speech of the BIM manager delivered privately to me. The meetings, the consultations and the speeches were registered by 200 hours of audio recordings in addition to a large volume of textual notes taken while observing designers working on Revit. This entire database was assessed and interpreted however only the most relevant fragments are transcribed and discussed by the following text.

During the first weeks of the field research various theoretical methodologies for ethnographic field research[8] were tested. I've attempted to describe subjects, actors, objects and roles, and develop interviews based on notes that were systematically taken and color-coded by actor and function.

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[8] Latour, Bruno (2005). Reassembling the Social - An Introduction to Actor-Network-Theory. UK: Oxford.
Guérrin, F.; Laville, A.; Daniellou, F.; Duraffourg, J.; Kerguelen, A (2001). Compreender o Trabalho para Trannsformá-lo - a pratica da ergonomia. SP: Edgard Blücher Ltda.
Geertz, Clifford (1973). The Interpretation of Cultures. NY: HarperCollins Pb, Inc.

However, the methodology developed by one of the authors of this work - Ergonomic Analysis of Activity[9] - was the dominant model for observing the design process. The methodology consists of observing an action or a meeting, distant enough from the action performed to not interfere but at the same time allowing the observer to register it by notes and audio recordings. Once the action was complete the architect was asked to describe it by answering three questions: (1) What were you supposed to be doing? (2) What did you actually do? and (3) How did you do it? The answers to these questions were than confronted with my notes, audio records and the literature. Many contradictions and discrepancies were found and are discussed by this text. The main actors in my descriptions were the BIM software Revit and the behavior it imposed on the design team. People and projects had a secondary role. The decision to consider Revit an active actor of the design process is a direct influence from Actor-Network-Theory proposed by Latour. However, Latour suggests that objects should have the same weight as the living actors, and the focus should be on the connections among them, instead I focused my observations on the object and the actions it induced.

The work performed by the group observed encompasses all the stages of the design process - schematic design, design development, planning permit and construction drawings. However, Revit neither strengthened nor weakened any design stage or project in particular. As the research progressed, it became apparent that the functionalities of Revit, its efficacies and flaws, evenly permeated all the design stages observed. Therefore, the transcripts presented below are organized by *topic* rather than project or design phase.

2.3 Over detailing

The biggest conference room in the company had been reserved for me through the morning period of my first day of field research. I was to use the room to introduce myself and present my research project. All the staff was invited to attend, including the architects, I was already assigned to observe. The conference started at 9:15 am, there was sixteen people in the room. I spoke for roughly 20 minutes. At the end of the presentation I started answering questions about my procedures for

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[9] Besides his academic research projects, the referred author has an extensive consulting experience in Ergonomic Analyses of Activity. For the past 20 years, his research projects and his teams have been systematically commissioned by Petrobras (Brazilian Oil Company), among other companies, to study and implement improvements on the work performed. His consulting is based on prolonged site observations performed by him and his team and a later analysis and interpretation of the data collected. Besides the theoretical framework mentioned in this paragraph, much of the methodology we used comes from his personal experience from consulting work.

collecting and registering information but didn't take me too long to notice some tension among the participants. It was when the BIM manager, without been asked, started a speech about what BIM was. His speech triggered a passionate argument among the audience. From that moment on I kept quiet, let them talk among themselves and started recording. The audience was clearly using the meeting as opportunity to discuss ongoing issues. It seemed that the staff was divided in two competing teams, BIM supporters and BIM non-supporters. The following text will show transcriptions of the meeting followed by our interpretation:

BIM manager: *"Revit is a tool, it could be BIM, it could not be BIM. BIM is a defined managed process that will vary depending on the typology of the project, owners' needs and capability of the team. And that's when we sit to discuss. We are also sitting in a place right now where our owners and contractors don't need that super crazy data layered, nor they wanna pay for that."*

Architect B: *"To me that is the frustration about the design process in Revit, and we had the same conversation with CAD. It depends of the operator I am working with, and the level of detail they want to input in the model. When they demand me to define too many dimensions in a schematic design, to me this gets in the way of what we want to accomplish, which is just documenting a conceptual design. If it is a schematic design for pricing purposes or to present to the owner just for them to conceptualize the design, we don't need that much information. Even if we throw away the schematic design and start over, it still less time consuming. We do it for the sake of the operator."*

BIM manager: *"You don't have to do it!"*

Architect B: "*I know but the operators demand it. There is a problem between conceptual design and documentation, but the design continues in between."*

Architect C: *"Another day I had a discussion about the thickness of a wall that was shown in the model with 4 inches but the drawings were showing it with 2 inches only. This was driving the entire conversation about a conceptual design. It is a huge disadvantage. I can use a thin pen or a thick pen to draw my wall and show the concept without defining the final thickness of it. We often have to input information and change it later on. I can feel the frustration of the operators when they need to change information and ask why didn't you give me the correct information in the first place? I say: Well, we didn't know yet the sizes the bolts were!"*

Architect D: *"This is a constant battle. Just like when the interior design team say they can't put the light in the model because they don't know what that light is yet!"*

Architect E: *"…but we didn't know what we didn't know. We can feel the frustration of the operator."*

BIM manager: *"But things always get harder to change as it gets later in the process. whether is in CAD or Revit. If you wait until constructions documents to change, its gonna suck, regardless. But you can do as sketch. You can use a 6 inches' wall or a 2-inch wall, you've got to use something. Sometimes you need to remodel everything, sometimes you need to remodel only part of it. We can hand over our model to the contractor and they will struggle a lot because the model won't do what they need it to do! Sometimes we need to start over because it makes more sense. We can train people to make the transition from design model to construction model but it takes a lot of software deep knowledge and I don't really think it make sense. We can't model with that level of detail. Nobody does that, it is insane. That drawing you showed me another day showing LODs 350 or 400s? It's got individual CMUs[10]! Nobody does that, even contractors don't do it. It is absurd, time consuming, insane."*

The examples described by the architects C and D - the specifications of walls or light fixtures - suggest that the level of detail induced by the software is inappropriate for several stages of the design. The *design intent stage* that this group was referring to is a set of drawings used for a series of purposes: discussing the project with the stakeholders, pricing and bidding, and planning purposes. Details such as specifications of walls or light fixtures are not part of any documentation intended for this kind of negotiation. In a bidding process for instance, the specifications should be as generic as possible in order to allow the bidding participants to suggest the specifications that best fit the budged and goal of the project. It does not mean that these specifications are inaccurate or do not carry the design intent. They should contain all the accurate dimensions, intended materials, etc. but without suggesting any specific brand. The same rationale applies for planning permissions. A project granted with permit by local authorities[11] should not impose specific brands for the building parts. It might suggest that the public sector is favoring a single company and not letting the market choose the best product. Besides, construction may take while to start and by the time the part is to be put in place it

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[10] LOD350 stands for Level Of Development 350. It measures how much detail has been modeled. CMU stands for Concrete Masonry Unit. It is a concrete brick.

[11] Construction works that impacts surrounding areas will require permission from local authorities. The local authority responsible for evaluate the project and grant the permission will vary from country to country as well as the process is given different names. In England the process is called planning permit. It is judged and granted by the local Council. In US the same process is called building permit and it is granted by the County. In Brazil the process is granted by the city hall and is called "approval by the city hall". Different local authorities will have different requirements, related to local demands and safety issues, in order to grant a permission for construction. Although the process is different from country to country, its nature is the same, any medium to large scale project will need permission from a local authority in order to start construction.

might not even be available in the market anymore. The design process is a sequence of negotiations that are susceptible to change even after the process is completed: part replacements, renovations and or reconversions are current practice of every building. The ideal design tool should guarantee precise and smooth negotiations at any time of the process.

According to the excerpt taken from the BIM manager's commentary, producing a Revit model that meets these standards require computational knowledge that does not belong to architectural realm:

"We can train people to make the transition from design model to construction model but it takes a lot of software deep knowledge and I don't really think it make sense."

The discussion transcribed above illustrates the overall in-satisfaction with the level of detail induced by Revit.

2.4 Software Standards

Maturity models suggest that projects developed by stakeholders that have the same level of BIM implementation would be highly efficient. However, the excerpt below demonstrates otherwise. Even though the companies involved had the same level of BIM implementation, individual software setups have greatly impacted the progress of the project. The following dialogue was taken from a BIM consultation at the BIM manager's desk. Architect A reported to the BIM manager a recurrent flaw in many of the projects he was involved with - building parts modeled in Revit were ignored, by the same software, when the model had to be opened and used by an external consultant.

Architect A: *"We always think that if it is in the model it is there, but if they don't see it, it is not there. So what they actually did was, they went back to the printouts, took out a highlighter and they highlighted all the missing parts! Because they have ignored literally hundreds of thousands of dollars of fire-ratings. And this happened many many times."*

BIM manager: "*This is one of the drawbacks of the model, there are a few ways we can view the model, they will link our model to their model but if their model is not setup with the exact same* *parameters, exact the same filters as our model, they will never gonna see what we see! We went through this thing of creating color-coded fire ratings for all the walls but it only shows in our model because of all the filters and parameters we have turned on*".

In this occasion, BIM did not facilitate the data exchange as expected. It had created an additional task in the process: double-checking the model by cross-referencing it with printouts produced from the correct BIM model setup.

2.5 The Shared Model

The conversation below was extracted from a BIM meeting. The following transcript illustrates a communication flaw with external consultants.

BIM manager: *"Our file does sync to the cloud, everybody can see your synchronization regardless where they are. However, it does not update the version of the model even though the date is sitting up there in the cloud, so when the consultant download the model, they are downloading whatever the hell it was there at the beginning of the project. I was going around and round with the consultants on this and it was like: "I don't understand why you are not seeing what I see from my end. And then today I downloaded from the cloud and opened it in my computer and boom, it was a version I uploaded two years ago! So, I called Autodesk and they said we've got to republish the model! It is not only upload it from our end for whoever download from their end. It is not rational. There is a sneaky little button on the window 'collaboration' for Revit that says 'republish it', And that is not terribly clear written in the Autodesk work flow. When you open the cloud models you will see all the old models but everyone needs to sync and republish it in other to keep the "downloadable" model up to date. The external people will only see the most recent published. From now own we agreed to republish our models every Tuesday, wherever they are on the evolution stage"*

This fragment above describes a file-sharing operation in practice, a BIM-associated procedure that could potentially facilitate the management of the design. File-sharing is possibly the most important requirement for qualifying as BIM level 3 at NBS maturity scale (or 5 at the scale proposed by Succar et all). Although the company's BIM maturity could score level 3 at NBS scale, the interface of the platform was still not intuitive enough to let them to perform ordinary operations associated to the BIM level the company was proficient to perform. After extensive research the BIM manager identified the problem and found the solution; however, this solution may not be permanent. Solutions and standards are usually applicable to a specific software version. Newer versions will require different solutions.

It is important to highlight that file-sharing is not a feature restricted to the digital environment. Before computation, the blueprints also had to reach the external consultants and stakeholder, either by mail or other analog transportation. These blueprints were put underneath tracing paper and used as a reference, the base file. This reference would be updated and sent back to its origin and other consultants for further development. The newer electronic versions of file-sharing are far more efficient, yet they still performing the same role. The flaw described above lasted for two years before the solution was found. Meanwhile the team had to use alternative paths to deal with the problem.

2.6 BIM level 5 (**level 3 of NBS scale)** ***and Facility Management***

The Revit model supposedly provides data to be used for Facility Management. The primary purpose of a Revit file at SLinUS is to develop and generate the contractual documents. Yet the clients of SLinUS were increasingly coming to expect that the Revit file, developed throughout the design process, could respond to Facility Management requirements. They ignored, however, the additional costs of these specially commissioned and produced Revit files. Intending to temper their clients' expectations, SLinUS partners called a meeting with the BIM manager to discuss the implications of including the final Revit file in the contractual document sets. The fragment below is a dialog between the BIM manager and Architect D that happened right after the meeting.

BIM manager: *Just came out of a meeting with partner M about contractual stuff electronic file transfer.*

Architect D: *You mean the model?*

BIM manager: *Well, our contracts are about creating paper. We create PDFs, we create Plans, etc. We are obviously using the model to create the documents, at the same time we also want to disavow our own knowledge of the model that was used to create the documents, because the documents are the official thing. If we share the model with someone, and say "you can have the model but! Don't trust* *the model, don't use the model for anything besides just looking at the model. Don't try to do quantity take off the model. We didn't do the model to do quantity take off. We did the model to make the contractual documents and doing so we may or may not have modeled all the things that we needed to model to throw it in a piece of paper, that's why Revit has 2D lines. If someone want to use our model to count the number of windows, there is the instance where we might have had to do a window as a piece of special equipment for some reason because of something. so, the counted one would be off. We are doing BIM BUT, we are not really doing BIM, we are using REVIT to create contract documents which give us BIM capabilities of which we're not really harnessing all it. They can use it as a supplemental type of thing. The PDF documents are, still our contractual documents. It is also a liability thing, if they need to take any numbers they will need to double check on paper, old school. The reason we are not doing BIM is not because we don't want. When we break down the costs to build a model that suits the client's - owner's management facilities' needs, they don't want to pay for it. It can increase from 50% of the cost of the project up to as much as the project itself. Depending on the complexity of the project it can double the cost.*

Architect D: *Why is the cost so high?*

BIM manager: *It is about pure data entry and the only way to do it is with people! I can put an intern to do it, but still. It is time-consuming and to get the right data, on the right time it is also another challenge that may screw the whole schedule. The other point is, many things need to be decided much later in the process. Doors for example, we specify a kind of door. There may be 3 or 4 door suppliers that can offer this specific door. By the time the doors will be put in place some of the doors we suggested may not be available on the market anymore. There is no way to know the final decision of some details, it is the contractors call. This is the nature of this industry! Even with brick! We specify the color and we give them 2 or 3 manufacturers that provide this color but, it may take 3 to 5 years for the contractor to purchase the bricks, and by then, we don't even know if the manufacturer will still exist! Even when the contractors are on board from early stages. They are not making any decisions about doors or bricks or windows. Even if they were designing they needed to be talking to the manufacturers and come to us "look we talk to this much of manufacturers and we got a really good deal with this one and we gonna go for this one". It might happen in a IPD situation where you got the owner, the contractor and the architect, all three as a team working together. But that is rare!!! If I could have that much of date to input in the model at the beginning of the process, that would make viable to deliver the model as a checking object, but the cost behind that is absurd. So on our contracts we give the model but we state, "you can't make copies of it, We don't assure the completeness and* *accuracy of the model – because the model was made to generate drawings, again I may have 2D objects that only shown on 2D drawings but don't carry any more relevant data." To make a model that is accurate enough to take quantity take-off it will cost a fortune. Making certain decisions early on the process, tracing down the numbers, adding the data. It still taking a lot of effort. Still a lot of money.*

The ultimate goal of BIM level 5 is to provide a 3D model suitable for owner's Facility management. In the literature, there are frequent claims (Eastman 2011) that the final BIM model will respond to the owner's needs if the project is developed in a highly integrated way, with all the stakeholders – owners, designers, contractors and subcontractors – involved from the early stages of the process. Such claims are embedded in two fallacies: (1) that the model is continuously updated during construction to reflect changes in the field; and (2) that highly collaborative projects are the majority of the AEC industry. These ideas do not match the facts, since in most cases, the constructor is hired through a bidding process only after the design is concluded. Designers convey the BIM model to the hired constructor and subcontractors. Not surprisingly, this model can undergo significant changes, particularly in consideration of the additional intellectual ownership issues and contractual liabilities. Usually, the information necessary for FM is further apart since some of the stakeholders who own the information have probably never met and the responsibility of collecting and organizing the FM data becomes cloudy. This can mean not only additional costs to contracts but often a new contractual agreement altogether.

A few days after the dialog transcribed above one of SLinUS clients expressed interest in commissioning the Revit file to be used as source for FM software. The BIM manager started to work on a brochure about 'Revit file for FM' to present to this client. The same brochure would serve to sell the service to other clients. When the brochure was ready for the presentation he came to my desk to show it and talk about the new venture:

BIM manager: *One of our clients officially wants the Revit for FM! I'd want to take the opportunity to start offering this for other clients! The way it works is that any facility management data doesn't come during the design time. It comes during construction, it is the contractor that picks the final HV/AC units, elevators, etc. They collect all the warranties, manuals, things like that. This is part of an as-built* *model, and we, very rarely, deliver it. After the design leaves our hands, it is the contractor that does all the final coordination, final drawings, final everything. They are in control of the final as built. If I can get out ahead of the curve, offering all these services. The client is a hospital group, they multitude of campuses across the country. All of their documents, plans are in still in paper, You know, hospitals, or any big program, they are going to be doing renovations constantly. So during the design meeting they told us that they want to "go digital" get rid of the paper plan situation! The challenge was to tell them what that means without scaring them and bring the project to us. So, the idea is to bring everyone, contractors, sub-contractors with us and we work as a team to produce and collect existing data. Not only dimensions but also specifications etc. We would be responsible for compile the date and from then work with them as a partner in a long-term run.*

The client was very excited at the beginning, however when the cost was presented the client declined.

3 Final Remarks

Our literature review demonstrated that the measurement of BIM implementation and the assessment of BIM maturity levels remain highly theoretical. Due to the confidentiality and liability nature of the industry, they lack adequate empirical evidence of BIM applications and remain controversial in regard to BIM certification and its adoption as a mandatory platform. Aiming to start filling this void, in this paper we performed an assessment of BIM maturity based on ethnographic observations of an architectural practice: SlinUS. At SlinUS every architect as well as the external consultants were using Revit on its fullest and the projects were developed over a single, shared model system.

"Over-detailing" was one of the most discussed topics at SLinUS. Transcripts showed that the BIM software imposes levels of detail that are inappropriate for several stages of the design. Besides, simple decisions such as wall thickness or lighting specs not only disrupted the flow of the design process but also increased costs due to the need for later remodeling. However, the costs of over-detailing had already been acknowledged by the company at this stage: the BIM software was mainly used to produce the contractual documents, that is the 2D-plans. 'Quantity withdraws' were only possible if the model was specially commissioned with this purpose[12], which rarely happened. Interestingly some architects of SLinUS didn't considered that 'they were doing BIM', since the production of two-dimensional drawings in Revit was perceived as a function analogous to CAD software.

Despite the perception of some architects that didn't consider SLinUS was performing BIM, the company had been consistently using a file-sharing system for every project of the company, the ultimate requirement for achieving BIM level 5 (BIM level 3 NBS). However, the company frequently faced technical problems with the platform provider either for lack of intuitiveness of its interface or the constant software updates that required re-learning the software procedures and adjust the company's methods accordingly. Regardless the extension of the benefits argued by the literature, file-sharing, in our interpretation, is not a feature restricted to the digital environment. Before computation, the blueprints also had to be shared with professionals of different expertise. They needed to reach the external consultants and stakeholder, either by mail or other analog transportation. These blueprints were put underneath tracing paper and used as a reference, the base file. This reference would be updated and sent back to its origin and other consultants for further development. The newer electronic versions of file-sharing are far more efficient, yet they still performing the same role.

Another requirement that qualifies a company for the highest BIM level is the ability to construct a BIM model that complies with the owner's needs during and after the construction – a model that will provide data for FM (Facility Management). SLinUS was fully capable of delivering such a model however the highly collaborative projects, requirement to enable the construction of a FM model, were extremely rare. Furthermore, the production of an FM model can considerably increase the cost of the project due to the logistics needed to provide continuous updates during construction to reflect changes in the field. SLinUS clients usually intend to commission the full modeled Revit file during the settlement of the contractual agreement but they always decline when its costs are disclosed.

The transcriptions also raised a discussion about software standards. Literature about BIM maturity suggest that projects developed by stakeholders that have the same level of BIM implementation would

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[12] Certain building parts, when modeled in 3D can't provide the correct bi-dimensional view required for contractual documents. These building parts will therefore be drawn in 2D. Revit latest versions are providing 2D lines to allow the contractual documents to be produced correctly. These 2D lines do not retain the numerical parameters of the objects they are representing. Therefore, the withdraw of numerical information such as number of windows, areas, won't be correct.

be highly efficient. Our research showed that even though the companies involved had the same level of BIM implementation, individual software setups have greatly impacted the progress of the projects.

As already suggested by our literature review, BIM-level certification granted to a single company can be misleading. BIM maturity relates to the BIM level of the team as a whole, designers and consultants. The models that measure BIM maturity should therefore assess the proficiency with BIM software and proficiency with the BIM process among all the members of a team. Besides, all maturity models ignore the cost embedded in performing highly integrated projects. A company, such as SLinUS, that is able to perform BIM level 5 cannot guarantee that they will deliver the BIM level 5 for every project commissioned. They will ultimately rely on the client's willingness to pay the appropriated higher fee for delivering such a BIM model.

Our research demonstrated that the attempts to understand the relation between higher levels of BIM and efficiency do not realistically consider the costs. The majority of the projects that claim to have reached a high level of BIM maturity are typically developed within very exclusive contexts and receive enormous exposure in the media despite representing only a small portion of the AEC industry.

The advantages of BIM platforms over 2D-CAD are not as obvious as the advantages of 2D-CAD platforms over traditional hand drawing process (Pereira et al 2016). The benefits of BIM over CAD are still difficult to measure, according to Barlish et al (2012), because it is impossible to compare the costs and benefits between non-BIM and BIM projects unless the same project is carried out using both platforms, by the same team, at the same time. While such a research scenario is unlikely in consideration of both practicality and cost, it would nonetheless be the only approach that could guarantee reliable and consistent data for comparison.

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