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Development of Knowledge Management upon the use of BIM Technology

Master Thesis

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Acknowledgement

Like every cycle that comes to an end, there are a considerable number of individuals who pass through our lives and end up sharing our challenges and feelings as if they were theirs too.

To those, close friends or family, I leave my profound thanks for always lifting me and keeping me enthusiastic about running towards my goals and never losing focus on them. Without your bestowed love, life would be meaningless.

I express my deep satisfaction for having had such great masters during my passage throughout the most varied courses in this program. Your initiative and passion for transmitting your knowledge to future generations drive the innovation and development of our time.

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Conceptual Formulation
Master Thesis for Mr Eduardo Vendrusculo
Student number: 1913028 – Metropolia / S0572693 - HTW

Topic: Development of Knowledge Management upon the use of BIM Collaboration Format

Background

Knowledge has been always a landmark of human behaviour and evolution. Therefore, the domain of Knowledge Management (KM), which is derived from knowledge science, is key in many disciplines and has been largely responsible for the development of new technologies and improvement in innumerable industries. KM processes and tools support the organization and optimization of individual and team skills for better benchmarks and project results, inducing the same impact when related to the AEC area. The continuous development of how things are handled and cared for in the AEC project seeks better skills and knowledge of new processes and technologies related to data-based construction methodologies. BIM is one of such developments which has perceived benefits for AEC projects and revolutionized its deliveries. The ability of BIM into providing a centralized global context for data improves the actual methods being used for KM systems into AEC fields, which have been further enhanced by the creation of a BIM Collaboration Format (BCF) fostering real-time issues communication within project members. Thus far, the corresponding data - which has been stored in several different formats and files - has become fragmented and lousy to capture, catalogue and disseminate within its stakeholders [1, 3].

The continuous development during the lifecycle of a project, especially concerning the transition between the design to the executive phases, can be effectively captured and used for enhancement through knowledge management systems, which major goals are to improve productivity and teamwork among a knowledge-sharing platform. Therefore, given this short introduction, I seek along this paper - and the future research based on it - to link a two-way bridge between KM and BCF, providing a wide literature review before building a case study methodology based upon it. Moreover, the research will propose the integration of experienced-based knowledge within the use of BCF, allowing significant and continuous improvement in decision making while minimizing design flaws and clashes. As many experts claim, information technology is currently probably the best tool for effective knowledge management in an organization [1, 2, 3].

Research Questions

- What means Knowledge Management and why it has become such a core field?
- What is Information Management and how it differentiates from Knowledge Management?
- Can BIM/BCF be considered a Knowledge Management System? If so, how?
- How BCF can be used as a real-time tool enhancing experienced-based knowledge during design and execution phases?
- What practices and methods would make such a union effective and widely used within the branches of Architecture/Engineering/Construction projects?

Method

The research seeks to develop and analyse the implementation of knowledge management systems within the transition between the design and execution phases of a supposed construction project following an BIG Open BIM working methodology in a fully collaborative BCF platform environment.

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The idea is developed according to 4 different stages of execution. First, the document will provide an in-depth review of the literature on the subjects covered and their correlation within the AEC industry. The second phase will have a federated base model containing architectural, structural and hydraulic projects where failures will be indicated as occurring during the design and executive phase of the project and perceived and reported by either the BIM Manager or the responsible constructor on-site. In a third moment, the focus will shift to the analysis of the data brought during the second phase, relating the results with the valorisation of knowledge and the development of higher quality projects. The closure of the research will englobe the conclusion of the study followed by indications of future work and improvements in the field.

The files corresponding to each of the individual projects will all be translated into an IFC format for the construction of the so-called federated model, which will serve as the basis for this methodology. The model will be assembled through the Solibri Office application, and all information will be hoarded into a Common Data Environment (CDE) accessible to any alleged stakeholder. Thereafter, the assumptions of common failures that occur during the execution phase and that are not generally expected during the design phase will be defined, providing a future conceptual structure of information destined to be transformed into knowledge. In conclusion, the BIM Collaboration Format will serve as a Knowledge Management System, making use of real-time communication for the dissemination and creation of enhanced knowledge.

Timescale

July 2020: Introduction and collection of relevant material.
August – October 2020: Review and development of related literature.
November 2020 – February 2021: Design and methodology of the proposed research.
March – April 2021: Analyses of findings.
May 2021: Review and corrections of full research.
June 2021: Conclusion.
July 2021: Submission of the master’s thesis.
August – September 2021: Presentation preparation and final oral examination.

Resources

The literature review will be obtained from articles gathered in online research organizations such as science direct, ISI Web of Knowledge and Google Scholar. The Solibri software is fully accessible through a student license provided by the thesis supervisor and will be handled on my personal computer for all necessary analyses. The projects are provided by a Brazilian construction company and supplied by its owner, who maintained a professional relationship with the author and agreed to make them available for this research.

References

[1] A. Deshpande, S. Azhar und S. Amireddy, „A framework for a BIM-based knowledge management system,“ in *Creative Construction Conference 2014, CC2014*, Auburn, AL , 2014.

[2] S. A. Ganiyu und M. S. Çıdık, „Knowledge Management and BIM Practices: Towards a Conceptual BIM-Knowledge Framework,“ in *1st ΨPsycon International Conference*, Wolverhampton, UK. , 2018.

[3] buildingSMART, „BIM Collaboration Format (BCF),“ buildingSMART, n.d.. [Online]. Available: https://technical.buildingsmart.org/standards/bcf/. [Zugriff am 4 May 2021].

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Abstract

Knowledge management (KM) within the Architecture, Engineering and Construction (AEC) industry is restricted due to an overwhelming amount of disintegrated data, information, and knowledge. Such overload could positively impact a higher organization's performance, but instead, its fragmentation has led AEC organizations to the incapability to identify, retain, manage, and reuse the tremendous bulk of essential knowledge generated throughout the execution of projects. The crucial factors spawning this gap within the AEC industry lies in its tacit knowledge and the lack of intense communication and interoperability of information systems. We address these hurdles by evaluating the behaviour of a BIM-based platform - Solibri Office - aimed at the analysis and communication of construction projects issues, interlinked with the utilization of a BIM Collaboration Format (BCF) to propose live transmission of knowledge and information between construction experts in a real-world AEC context, strongly referencing the process to the knowledge creation theory (SECI Model). Thereunto for the idea to materialize, a case study was selected concerning an actual building under execution, which served as the basis for elaborating most of the critical evaluations of this research. Data, information, and knowledge were stored within a Common Data Environment (CDE) during the communication flow and finally provide the foundation for this research's main takeaways, where data and information were exploited to create knowledge. Through demonstrating the capabilities of BIM and, therefore, the utilization of BCF under a real-time web-based platform, it is hoped that this research enhances the view on the magnificent role of KM within the AEC industry and its advantageous applications.

Keywords: Knowledge Management (KM); Architecture, Engineering and Construction (AEC); BIM (Building Information Modelling); BIM Collaboration Format (BCF); Data, information, and knowledge.

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List of Abbreviations

AEC	Architecture, Engineering and Construction
AI	Artificial Intelligence
API	Application Programming Interface
BA	Business Analytics System
BCF	BIM Collaboration Format
BI	Business Intelligence System
BIM	Building Information Modelling
BS	BIM Standard
BSI	British Standard Institution
CAD	Computer-Aided Design
CDE	Common Data Environment
CEO	Chief Executive Officer
DIK	Data, Information and Knowledge
DIKW	Data, Information, Knowledge and Wisdom
Dr	Doctor
DSS	Decision Support System
EIS	Executive Information System
EN	English Language Version
ESS	Executive Support System
Et al.	Et Alia - “And Others”
E.g.	Exempli Gratia - “For Example”
HTW	Hochschule für Technik und Wirtschaft
HVAC	Heating, Ventilation and Air Conditioning
ID	Identification
IFC	Industry Foundation Classes Format
IM	Information Management
IS	Information System
ISG	International Implementation Support Group
ISO	International Organization for Standardization
IT	Information Technology
I.e.	Id Est - “That Is”
KM	Knowledge Management

KPI	Key Performance Indicator
LOD	Level of Detail
MEP	Mechanical, Electrical and Plumbing
MIS	Management Information Systems
MM	Modeling Methodology
Mr	Mister
NBS	National BIM Object Standard
OLAP	Online Analytical Processing
OM	Organizational Memory
OMIS	Organizational Memory Information Systems
P&O	Protocol and Information Organization
PAS	Publicly Available Specification
PEP	Project Execution Plan
QA	Quality Assurance
QC	Quality Checking
RVT	Revit
SECI	Socialization, Externalization, Combination and Internalization
TPS	Transaction Processing System
UK	United Kingdom
URL	Uniform Resource Locator
WPI	Work in Progress

List of Symbols

m^2	Square Meter
%	Percent
&	And
£	Pound Sterling

1. Introduction

The success of the architecture, engineering, and construction (AEC) industry is heavily attributed to individuals and understanding human behaviour throughout construction projects[1]. Closely linked to the most favourable outcomes are the management of knowledge and information, which information technology (IT) systems highly support today[2].

Therefore, the purpose of this research is to develop and evaluate a cloud-based BIM platform as an intelligent system to improve Knowledge Management (KM) within a context that could be addressed to real-world AEC issues faced during the design and execution of construction projects.

Based on my knowledge and experience about how BIM has been improving the communication and collaboration between construction professionals and how the retention of tacit knowledge within the AEC industry is abundant, I have decided to bond both together and propose a methodology that would enable the retention and creation of knowledge by an organization, firmly based on the principles of the knowledge creation methodology proposed by Nonaka during the 90s.[3]

While researching for methods by which I could interlink the two elements, I came across the use of BCF though software providing real-time communication of project issues. This application method allowed me a perception that, in addition to the natural capture of knowledge for the communication of errors outlined by the verification of clashes, the involved professionals could add even more to this tool, contributing with additional information retrieved from their experiential knowledge of years of work-life.

Hence, real-time BCF linked to a Common Data Environment (CDE) appeared to be a substantial technique to enhance KM within the AEC, giving its roots in the BIM methodology and its representativeness as an innovative method of improving communication.[4] This research is thus brought together under the three major disciplines within the AEC industry of Knowledge Management, BIM and BCF real-time applications.

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[1] Arif et al. 2008.
[2] Kuo 2019.
[3] KMT 2018.
[4] Natrop 2020.

1.1 Problem Synopsis

As Bender and Fish (2000) pointed out, while the expertise of professionals cannot be transferred, employees walk in and out of companies' doors carrying their entire knowledge with them. This argument marks the central problem addressed by this research, the vanished knowledge within organizations.

AEC industry is famously recognized as being a knowledge-intensive industry relying on information from several fields of activity. Hence, it accumulates vast amounts of knowledge and data for each specific project, whether explicit and documented or tacit and kept within its various professionals accumulating years of experience and personal knowledge, which within this field is even harder to file and manage compared to others.[5]

Such hardship arises from the decentralized spectrum of the AEC industry, which results in wholly defragmented data hard to synthesise and formalise[6]. In order to be useful for knowledge management practices, such data must be harmonized and targeted to the right people at the right time[7]. In this sense, the concern of this paper is to provide easy and logical means to find the appropriate sources, incorporation and giving sense to the excessive extent of data while proposing knowledge aimed to support both decision-making within the company executive sector and the retention of knowledge aided to future developments and the newcomers.

Although today the quantity of tools and practices encouraging the KM is manifold, there is still a great hardship to apply them to companies. Whilst for organizations, data means power and power means market advantages, problems like overload, data interoperability and the perplex socio-technological dimension are still significant challenges of tacit knowledge management[8]. Without adequately addressing these barriers, knowledge management practices are meant to fail, bringing about only adverse outcomes instead of benefits.

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[5] Designing Buildings Wiki 2021 (3).
[6] Fong 2005.
[7] Arif et al. 2008.
[8] Kuo 2019.

1.2 Research Questions

This research is driven by five important questions aimed to be answered successively throughout the development of a literature review and thereafter a proposed methodology. They are:

1. What means Knowledge Management and why it has become such a core field?
2. What is Information Management and how it differentiates from Knowledge Management?
3. Can BIM/BCF be considered a Knowledge Management System? If so, how?
4. How can BCF be used as a real-time tool enhancing experienced-based knowledge during design and execution phases?
5. What practices and methods would make such a union effective and widely used within the branches of Architecture/Engineering/Construction projects?

Together they address the core of this research, aiming to develop knowledge management within the AEC industry by using a BCF real-time cloud-based platform. It is vital to bear in mind that the feedback to those questions deepens the understanding of the matters and their possible relations but does not seek to improve the software or their IT functions. The proposal of enhanced use of the provided tools for the industry by attempting to excel some significant challenges is the leading and only goal upon creating and resolving this investigation.

1.3 Methodology

The research includes the following methods:

- A literature review and an in-depth analysis of the main subjects surrounding this thesis.
- Analysis of a real-life case study from which primary and secondary data can be studied, structuring the outcomes towards knowledge creation.
- Computational methods using Solibri Office Software and BIM Track web-based platform introducing a collaborative methodology based on BCF real-time communication between stakeholders.
- A final analysis of how knowledge can be created based upon data and information supporting organizations' necessities.

The methodological structure proposed for this research aimed to introduce the matters to the reader before moving towards a case study and my personal view upon how, by incentivising individuals to share their knowledge through a communication platform, knowledge management could be achieved. Furthermore, it was structured to provide a smoother comprehension and succession of the methods, enabling the reader to understand step by step of its development process.

1.4 Research Structure Outline

The development of the previous methods responds to their impact on answering the proposed questions addressed by this research. In evaluating this, the research was thought and structured within the requirements imposed by the institutions governing this international master's programme.

Following the introductory chapter, chapters two to five embrace the literature study of this research, portraying after a concise presentation of the sections a comprehensive understanding of the critical subjects addressed throughout this entire paper. Nevertheless, it is worthy of highlighting that the aim of the literature review proposed within these early chapters is to enable the reader to understand and appreciate the subjects and the research problems fully.

Chapter six announces the starting of the research methodology, indicating the case study under evaluation and breaking down the building and its designs, providing a spectrum of the entire development and its models. Moreover, the federated model is put together, and the opted CDE for further analysis is pointed out.

Chapter seven analysis the creation data during the design and execution phases of the case study, providing early insights into knowledge creation and sharing. Its content serves as a foundation for developing its following chapter, where the data and information collected up to that moment are structured into a knowledge source. Lastly, chapter nine concludes the entire research highlighting its main takeaways and the paths for further developing this research proposal idea within the industry.

2. Literature Review

A complete literature review is provided to address appropriate content and information regarding this research topic among the following chapters. Alongside, a collection of relevant authors introduces the respective matters and points out pertinent questions upon their current developments. The literature varies from articles gathered on internet research tools to renowned scientific books. The author's selection relied upon the significance of their documents in developing the subjects' past and present evolution.

Two significant factors define this paper as being widely based on web research and online libraries: first and most significant is the ease with which documents from all around the world can be tracked and accessed, resulting in a massive range of resources and information regarding the matters; and the second main factor is the pandemic situation (Covid-19) we find ourselves in while this document is being written, which, although unusual and unexpected, has created a barrier towards greater access to libraries and physical papers. Hence, highly rated pages such as Web of Science, Science Direct and Google Scholar Scopus are widely used throughout this research, both through access provided by universities and through open access documents.

Furthermore, the selection of authors ranged between names as creators and revolutionaries in deferred fields, from which the core of theories could be found, analysed, and understood, as well as modern names and developments that portray the situation and evolution of the fields up to today. Combining both provided an in-depth investigation answering the first two theoretical questions of this research while providing a concrete base for resolving the following.

Introduced from an in-depth review and understanding of the meaning of Knowledge Management (KM), this paper dived into its connection within the construction industry, highlighting the importance of such correlation and the flaws in following the technological pace we witness today. Building Information Modelling (BIM) stands as the methodology emphasised to expose interrelationship between the subjects, highlighting its vast importance to the AEC industry.

3. Knowledge Management

This fusion of two very known and widespread words as “knowledge” and “management” may go unnoticed many times, but they carry great significance in the natural development of society and preach an essential factor when related to the business world. Although the description of their values is also described, attention is on the entire context that both represent together.

The term “knowledge” is the most known and widespread in the literature, and it dates from centuries ago. It derives from knowing and can be associated with several activities in which one acquires an understanding of something, capabilities or even skills. It naturally derives from personal developments or set sources of information and data[9]. “Management”, on the other hand, represents the know-how of coordinating and administrating such data to achieve one or more goals. Therefore, KM can be regarded as a set of approaches within an organization’s available resources and staff to enhance its performance. Modern management, as we know it, was originated in the 16th century and thus far has consisted of the same core principles of organizing, planning, controlling, and directing resources within a corporation aiming its enhancement.[10]

Despite the several classifications of “Knowledge Management”, its denomination as a field of study is unclear throughout history. Learning about what knowledge is capable of and its advantages when being managed date from decades ago. For instance, during the second world war, Germans were already putting the theory in practice, when serial aircraft construction notably became not only faster but much more efficient throughout its constructive lifecycle based on learning from their fails and successes – a lethal but great example for exposing the effectiveness of such a methodology.[11]

Nonetheless, Prusak (2001), one of the most renowned names of KM literature and a precursor of its study as a subject, suggested a conference held in Boston and organized by him and other several colleagues – which by the time were a small group of KM interested people who began to talk and research over it – in early 1993 as a starting point mark[12]. His suggestion was this date due to being the first time an event

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[9] Merriam-Webster 2020.
[10] BusinessDictionary n.d.
[11] Prusak 2001.
[12] Prusak 2001.

was dedicated only to discussing the matter, where ideas and proposals were discussed and carried out. Such a mark elevated KM to a deeper level of understating and enhancement, opening its way for broader acceptance, study, and further interest from enterprises.[13]

According to reports of the same, the event counted with a significant number of specialists and visitors interested in the workability of knowledge within their own companies, driving it into being the subject's more significant milestone till the date and, hence, widely recognized and accepted through different researchers as the initial mark for knowledge management as a subject related.[14]

Thereafter, definitions and citations started to pop up around interested parties. One of the most cited and recognized definitions of knowledge management until today was coined by O'Dell and Grayson in 1998. The authors intelligibly defined it as: *"Knowledge Management is therefore a conscious strategy of getting the right knowledge to the right people at the right time and helping people share and put information into action in ways that strive to improve organizational performance"*[15].

Despite its simplicity of conception, it implies a great effort into creating solid ties of comprehensibility within a company, identifying though where and in which form the knowledge stands, how the organizational processes are structured and how to ensure that such enhancement of knowledge-based initiatives will have a good flow of acceptance and support by the organizational members.[16]

The collection of definitions for knowledge management may still contain assorted other forms according to the relation used by authors within their fields of specialization since the matter is based on a multidisciplinary nature. Nonetheless, when going through its literature, one is quickly faced with the repetition of four representative verbs worth mentioning: use, create, share, and manage. They represent the core of KM systems, independently of their area of performance. Girard and Girard (2015), researching its meaning and definition, concluded that knowledge management is commonly defined as a *"process of creating, sharing, using and managing the knowledge*

[13] Girard & Girard 2015.
[14] Girard & Girard 2015.
[15] O'Dell & Grayson 1998, p. 8.
[16] KMT 2018.

and information of an organization", disregarding the branch of study is being implemented.[17]

3.1 Knowledge, Information and Data

Following the prior definition of "knowledge", one must be identified with the meaning of "data" and "information" before delving into this paper. Even though the word "knowledge" can mistakenly provide a similar meaning for "information" throughout the literature, business and other disciplines are essential to define both as different practices and, hence, definitions.

There are two types of pyramidal figures which are commonly found among different authors to explain their linkage. One uses the three previously related words, composed of data at its base, information occupying the middle and, finally, knowledge at the summit. The second is followed by the same arrangement adding "wisdom" to the top of the hierarchy, regarding it the output of the four-level design. Respectively, they are often quoted as the DIK and DIKW models. The interrelation within whether the triple or the quadrupled system provides the foundations for developing management systems[18].

The figure below depicts the distribution of these terms through the four different stages. Although wisdom is depicted in the figure, it works only as further additional information to the subject, since the understanding of the first three pyramidal stages by the view of the author constitutes sufficient information for the understanding of KM and the purpose of this research, hence only further explaining data, information, and knowledge. They are decisive when building up the whole meaning of the term "knowledge".

[17] Girard & Girard 2015, p. 14.
[18] KMT 2018.

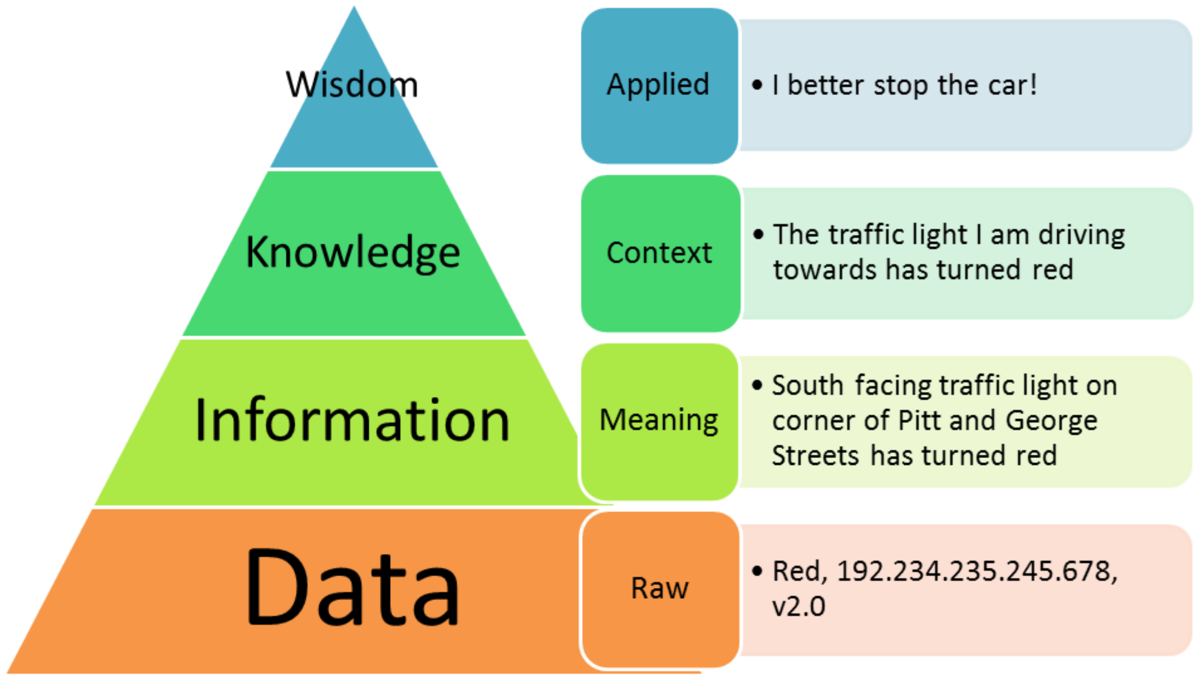

Figure 1: DIKW Pyramidal Model[19]

At the lowest form, data is classified as being raw, unstructured, and unorganized material that needs to be connected to some context to achieve meaning. In other words, data, when left alone or unlinked, becomes meaningless. It can be a fact, number, symbol, statistics or made up in many other ways, which might be further analysed to become information. Generated data is often collected and measured based upon observations of whether a person or a machine, being independent and relying only on itself to exist. Regardless of the field, the amount of data drives our present enhancements and what it will do with our future ones.[20]

Such significant importance has led to what we now call “Big Data”, which as the name describes, is a large proportion of data that needs to be stored and processed. Organizations have waged a "race" of data acquisition, believing (and with concrete reasons) that as higher is the data they hold, the higher is their competitiveness in the market. Several books and authors attribute the evolution of our era – concerning most of the industries – to the amount of data that an organization can own, storing and process. Simply, as more remarkable is the data one acquires, the greater is the respective

[19] McDonald 2011.
[20] DATAROB 2020.

information, knowledge and enhancement followed by it. Hence, more significant is the organization's power. [21]

Following the pyramidal structure comes the information, which provides meaning to data and represents a more complex level. Through the information, one can read and access the stored data in an organized, structured, and continuous form. Briefly, data now has a direction and purpose. For instance, a great variety of numbers and facts regarding pricing and quantities of a year-production of a company may not mean much. However, departing from a deeper analysis, they can tell one how much that organization has profited during such year or how much it could higher profit if better systemized – conveying data into something specific and valuable for the corporation. Hence, information is entirely dependent on data, being inexistent without the presence of it.[22]

A few attributes will determine whether the information is quality reliable or not, such as accuracy, level of relevance and detail, age, and completeness[23]. Ultimately, the way organizations process data has proven to be the key to improvement and success, leading them to adopt the right decisions to achieve the right goals. Data collection and processing mechanisms are recognized as Information Systems (IS), highly based nowadays on new technologies and IT tools to store, process, and share information among the organization's stakeholders. IS are the software and hardware supporting data-intensive applications, covering areas such as data management.[24]

Next to the brief description given at the beginning of this chapter, knowledge represents a deeper understanding of "what" and "how" to handle information. Information becomes knowledge when human experience is applied, shortly meaning that which one knows. Moreover, it accumulates over time through either new learnings or long-term experiences on repetitive activities, originating through classification degrees of expertise. For instance, someone who has shown excellent knowledge in computer science and hence aptitude for a given job position due to years involved with the subject against one with little or no knowledge on the matter, therefore strictly representing one's related experience.[25]

[21] GARCIA 2020.
[22] DATAROB 2020.
[23] Manhanta 2018.
[24] DATAROB 2020.
[25] Manhanta 2018.

Among the various meanings and definitions surrounding "knowledge", one must recognize the different types to acquire complete comprehension of this management subject. After almost 30 years of accumulative studies, the field's evolution has been given within relatively important known disciplines as economics, sociology, philosophy, and psychology. Originated from the latter – specifically the cognitive branch of it – are the subjects of tacit (also recalled as "implicit") knowledge and explicit knowledge[26]. Both are extremely important, either serving as the core for management matters or as an essential foundation within an organization's team intentions to success and productivity. Furthermore, the embedded knowledge further clarifies the differences and usages of the subject.[27]

Nevertheless, following the advances of Information Technology (IT) and Artificial Intelligence (AI), it is prudent and correct to affirm that knowledge arises in a vast form of machine experiences and self-learning processes, consistent with a knowledge base of data and information stored within itself. As Dr Anthony J. Rhem (2017) points out, knowledge represents the core of both AI and KM, thence characterizing the "two sides of the same coin". While the latter focus on enhancing human performance based on knowledge to perform tasks and decision-making processes, the other eases it through enabling more outstanding management of data and information, expanding, and creating knowledge to unimaginable and humanly unreachable levels – characterizing such enhancement as only possible throughout the provision of computerized systems.[28]

3.2 Explicit, Tacit and Embedded Knowledge

According to importance levels, explicit and tacit knowledge place themselves first and deserve greater attention throughout this section. Baskerville and Dulipovici (2006) describe in simple terms their difference, referring to one as distinguishing information – regarded as "know-what" or explicit knowledge – and the other as combinational skills – "know-how" or tacit knowledge. KM organizations have generally rooted the

[26] Prusak 2001.
[27] Alexander 2018.
[28] Rhem 2017.

interaction and relationship of both into defining their paths, remaining a cornerstone of this discipline throughout the years.[29]

Reviewing the differences brought by the literature, Botha *et al.* (2008) have held vital considerations into identifying both as one single matter instead of two different subjects, therefore rating knowledge as a homogeneous mixture instead of heterogeneous. However, despite the everchanging ideas among researchers and authors, this paper emphasizes both as two different matters and depicts them separately, seeing them as beneficial for understanding their similarities and oppositions.

3.2.1 Explicit Knowledge

Explicit knowledge consists of data and information on documented and accessible forms, arousing from facts, policies, manuals, and several other examples of knowledge that can be conscientiously formalized and codified electronically or physically in the scheme of documents without further implications[30]. Explicit knowledge, therefore, becomes uncomplicated to process and manage. For the company, nonetheless, the imperative task remains to ensure that the knowledge is stored appropriately, being albeit easily accessible and retrievable to all interested parties.[31]

Updating, reviewing, and selecting stored documents and possibly less valid information is becoming increasingly indispensable to obtain high-quality information. That is by cause due to the faster information flow which faces our society nowadays, with internet-based connections exchanging data from all parts of the hemisphere in a matter of seconds. Because of such an accelerated pace, it has become challenging to keep up competitiveness based on old sources that do not represent actual data.[32]

3.2.2 Tacit Knowledge

By contrast, tacit knowledge completely disregards recording. The achievement garnered from life experiences and personal skills developed throughout time, therefore belonging to the individuals themselves and their capabilities[33]. Dissipation occurs

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[29] KMT 2018.
[30] Wyatt 2001.
[31] KMT 2018.
[32] KMT 2018.
[33] Wyatt 2001.

through personal apprenticeships and face-to-face contact between individuals, hence strongly characterized by human interactivity and will. Such qualities make it extremely difficult to document and be communicated.[34]

Moreover, such qualities frame it as more distinct and worthwhile than the previously explicit one, being it the turn-key enhancement of an organization and, more precisely, of the individual inserted on it. Gamble and Blackwell back in 2001 related the lack of innovations and sustainable evolution precisely with the lack of focus on tacit knowledge, and, even though almost 20 years have passed, it constitutes an even more effective truth.[35]

When understanding the knowledge stored in a person's brain, one must consider the whole cultural and social evolvement behind one's life[36]. Miscellaneous examples about how different individuals would act towards the same problems are vast through literature, explaining how one suffered from contrasting life experiences and teachings throughout their lives. It is evident that the way I write this paper is unique, and anyone else who would develop better writing would step upwards in a selection, notwithstanding we are basing ourselves on the same sources.

The table below extracted from Virkus (2014) aims to depict better the differences between described knowledge types based on their significant characteristics before moving on to the mutational possibility within them.

Explicit Knowledge	Tacit (Implicit) Knowledge
Objective, rational, technical	Subjective, cognitive, experiential learning
Structured	Personal
Fixed content	Context-sensitive/specific
Context independent	Dynamically created
Easy to share, externalized	Difficult to share, internalized
Easy to codify	Difficult to capture and codify
Easy to share	Difficult to share
Easily transferred/taught/learned	Hard to transfer/teach/learn
Exist in high volumes	It involves much human interpretation
Easily documented	Hard to document, has a high value

Table 1: Comparison Between Explicit and Tacit Knowledge[37]

[34] KMT 2018.
[35] KMT 2018.
[36] Botha et al 2008.
[37] In conformity with Virkus 2014.

Magalhães (2015), based on Nonaka and the famous SECI model, described the learning cycles surrounding the subject of knowledge management as being characterized by a spiral mode into which knowledge originates more knowledge, whether from the same domain or not, before being disseminated among stakeholders. From this point on, it is of extreme importance to understand the so-called “externalization” and “internalization”, respectively representing the tacit-to-explicit and explicit-to-tacit interrelationships - one regarded as the codification of tacit knowledge and the other as the training and practice of explicit. [38]

Profoundly, they correspond to an endless circle of knowledge generation and development which will be further depicted through this paper, ripening the matter itself and the organization. Thence, in the case of externalization, even with the flow of personnel from inside-out of the company, tacit knowledge might remain within its core instead of being adrift and taken away by one.[39]

Not long-ago employees would stay in the same company for years and, not unusually, for their whole career lives. That would mean his/her tacit knowledge would remain long enough within the company to evolve and to be shared among either less experienced colleagues or new professionals, keeping market competitiveness. Today is utterly the opposite; workers constantly switch jobs between competing companies, hardly building long-term careers. Hence, they carry all their knowledge gaps, leaving knowledge gaps into organizations that must be fulfilled without losing power and competitiveness. Additionally, the hardship of “externalization” operation, such milestone is broadly recognized as the most significant lever for either the company’s progress or decay. The issue results from the fact that turning personal knowledge and experience into documented know-how is far from an easy task, as well as developing knowledge already existent and considered explicit require years of study and clinical analysis.[40]

3.2.3 Embedded Knowledge

Although the most prominent discussion and reference to types of knowledge surround tacit and explicit models, embedded knowledge is sometimes overlooked – it might be

[38] Magalhães 2015.
[39] Magalhães 2015.
[40] Magalhães, 2015.

just as crucial as the formers for this subject. It provides the differentiation between the knowledge embodied in individuals – tacit – to the one embedded into processes, organizational cultures, routines, manuals, ethics conducts, and so on.[41]

Delivered as a plus for the first two related bits of knowledge, it can still be instrumental whenever an organization decides to deepen knowledge management and its benefits, keeping a tab whenever the analysis is needed and maintaining a valuable addition to the matter. Knowledge is formed either formally or informally embedded. That means, for instance, setting up initiatives or activities aimed at enhancing a company's well-being – formal – or as applied and executed by prior explicit and tacit knowledge – informal. If developed and executed with precision, which has proved to be an arduous goal, it represents significant competitive advantages in the market.[42]

3.3 Organizational Knowledge

Individual knowledge domain is defined as the individual's capability into drawing distinctions based on both context and theory of his actions and activities. Organization knowledge thus represents its collectiveness, mastering the understanding of the capability of each and all the members of one organization into drawing such individualities to carry out their works, by accomplishing sets of conclusions, interpretations whose application always relies on developed collective comprehensions.[43]

Thereby, tacit, explicit, and embedded knowledge shape the organizational terms of companies towards enhancement. Its comprehension materializes through business expertise being subdivided amid different associations of organizational knowledge resources as it follows.

- **Individual**: based on personal experiences and often tacit – even though holding the possibility of being explicit
- **Groups/Community**: it encompasses all three types of knowledge, and it is associated with the different groups existing in companies, whether they are hierarchical, operational, or even of standard practices as language and values. The knowledge held by such groups remains internalized within members

[41] Horvath 2000.
[42] Hajric 2018.
[43] Tsoukas and Vladimirou 2001.

- **Structural**: exclusively embedded-based knowledge which either many or few stakeholders may understand. A clear example is a knowledge embedded in daily routine exercises required by companies or even public bodies followed by employees who may not know and recognize it
- **Organizational**: Also regarded sometimes as organizational memory, it represents the retained knowledge of an entire organization. One of the most widespread definitions for it is brought by Hatch (2010): *"when group knowledge from several subunits or groups is combined and used to create new knowledge, the resulting tacit and explicit knowledge can be called organizational knowledge"*[44], therefore delineating the knowledge resources acquired by a company with the authentic possibility of application, either among individuals and groups or simply laying at the organization level itself
- **Extra-organizational**: Any variation of present knowledge that is drained from external sources to within the company and used for its internal enhancement[45]

Once again, starting from an individual perspective, one base oneself on theories and beliefs to generate personal judgments. The ability to exercise such judgments is termed in the literature as the creation of one's knowledge. Such a process generates specific findings resulted from the individual characteristics, driving towards different ideals from the same point. Superficially, this knowledge is organizational by simply being developed and transmitted within organizations. Deeply, one must also consider the contextuality of the present environment, creating distinctions in their actions based on embedded generic rules produced by the organization. Therefore, knowledge becomes embedded in storehouses and papers and organizational practices, routines, norms, and culture[46].[47]

Therefore, KM endeavours to identify and share the organization generated knowledge at all levels and facilities. That means promoting diffusion among individuals and groups according to the organization's rules and requirements, or, in other words, advocating the proper distribution of knowledge, whether coming from external or internal sources, where is most convenient to business enhancement. Nonetheless, as pointed

[44] Hatch 2010, p. 278.
[45] Hajric 2018.
[46] Omotayo 2015.
[47] Tsoukas and Vladimirou 2001.

out by Hajric (2018), the efficacy of KM will rely upon the understanding and management of organizational learning and memory, knowledge sharing and creation and organizational culture.[48]

3.3.1 Organizational Memory

The definition of memory is related to an individual and his brain faculty of acquiring, restore, retain, and retrieve data, information, and knowledge (the memories). In this sense, the three main processes of encoding, storage and retrieval are indispensable[49]. However, memory can also be regarded with collective connotation, applying it to organizations and groups of individuals, thence, characterised as organizational memory (OM), collective memory, or even corporate memory[50]. An organization's ability to benefit from such past experiences and to act effectively in future decisions is OM's most substantial relationship with knowledge.[51]

Organizational memory or knowledge repository is somewhat coined as “the memories” accumulated by a company throughout the years. The stored memories are easily accessible and hold a supportive aspect aiming at the mutual development of individuals and organizations. Concerning the first, it provides a range of knowledge to be grasped and added to one’s learnings and experiences, developing the individual himself. On the company side, aggregating stored and known knowledge from past experiences with newly conceived knowledge - originated from the interrelation of beings - produces a range of accumulated knowledge that can be used either as an aid to actions and decision-making or as to new development of solutions, products, and services.[52]

OM must be thought of as a mechanism in demand for constant development that needs to be fed all time. In this sense, organizations must hold a good strategic plan to create and maintain a ground/safe environment, incentivising and boosting its members to exchange information and knowledge uninterruptedly.[53]

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[48] Hajric 2018.
[49] Cherry 2020.
[50] Kaufmann *et al*. 2019.
[51] Ackerman & Malone 1990.
[52] Barros, et al. 2015.
[53] Barros, et al. 2015.

However, for higher performances to be achieved, a structure that allows a good information flow is essential. Throughout the literature, the most cited and regarded structural model is developed by some of the foremost researchers of organizational memory, Walsh and Ungson, depicted in figure 2. The model aims to explain how the information flow occurs through the concept of the internal components of the OM retention function, categorizing different levels of the environment and their respective processes.[54]

The information is not centrally stored; it is split into different repositories (retention facilities), represented by the central circle of the figure. Those repositories are mechanisms of memory retention, and therefore the information present within them is employed to generate further new information, knowledge, new processes or products, organizational learnings, and so further. The information or knowledge retrieved is reflexed into actions and decisions taken by individuals within an organization.[55] [56]

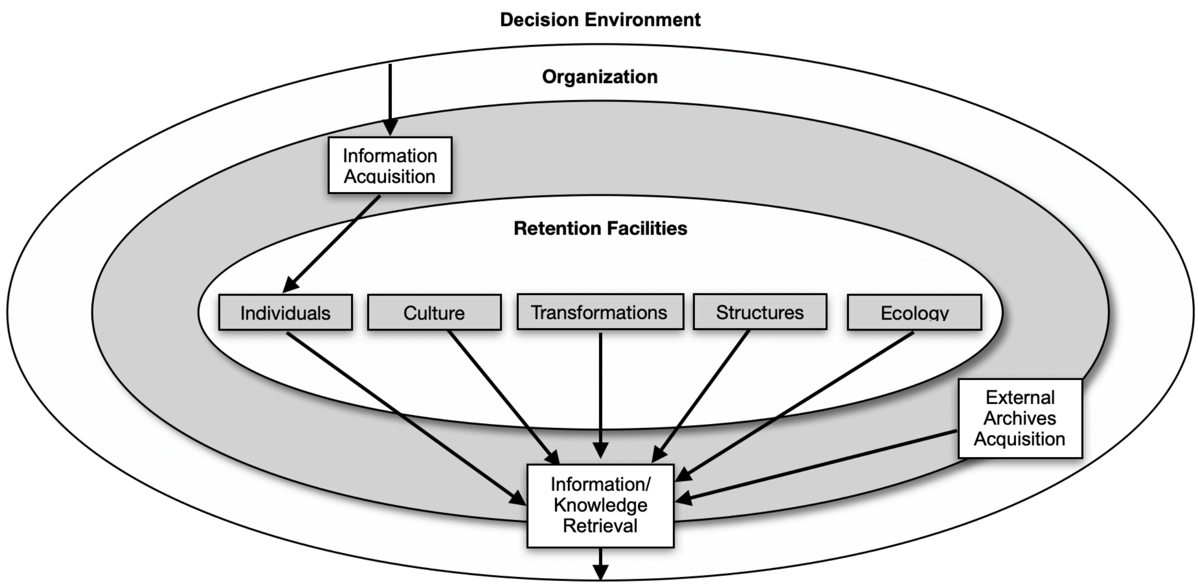

Figure 2: Structure of Organizational Memory[57]

According to the authors, it is crucial first to understand the nature of the individuals composing one organization to comprehend the acquisition, retention, and retrieval of information. In this sense, all internal and external factors involving an individual's

[54] Barros, et al. 2015.
[55] Barros, et al. 2015.
[56] Walsh & Ungson 1991.
[57] Adapted from Walsh & Ungson 1991, p. 64.

behaviour will directly affect the quality of final information being retrieved and thence the organization's attitude and actions.[58]

In addition to all internal forms of information retention, there are external activities. They are related to the organization's surroundings and, as in the case of the individual, are inserted in a social context weakened by information, whether from competitors, competing partners or companies, customers, associations, etc[59]. As Walsh and Ungson (1991) affirm, organizations are surrounded by others who adhere to their actions and, in the absence of essential information, they, like the other organizations, resort to external forms in the same context, thus creating an information flow environment independent of its internal repositories.[60]

Directly supporting this entire structural process are the information systems, which are extremely important for OM to facilitate the acquisition, retention, and dissemination of memories within an organization and its members. Furthermore, the "preservation of organizational memory" is within the core of IS, meaning that just as one enhances the performance of the other, IS is also totally dependent on OM. Such mutual work is referred to as OMS (Organization Memory Systems) or OMIS (Organizational Memory Information Systems) and in either way produce much more effective decision making, innovation and quality of products and services.[61]

3.3.2 Organizational Memory Systems

An organizational memory system is built upon information technologies such as data warehousing, document management, telecommunication links and search tools. These ITs, in turn, accentuate mostly the acquisition and storage of information and knowledge within OM, intending their dissemination among organizational members. An adequate information and knowledge process is therefore reckoned as the significant challenge of OMIS.[62]

Information systems exist to enhance the human's capabilities, such as memory and information processing, for instance, empowering one to cope with the common

[58] Barros, et al. 2015.
[59] Barros, et al. 2015.
[60] Walsh & Ungson 1991.
[61] Perez & Ramos 2013.
[62] Barros, et al. 2015.

overload of information. Thus, it can be said that IS tends to focus more on concrete memory and less on informal structures, attaining a higher focus on artefacts of cooperation. This interface human-machine provides inputs for the individual in his cognitive process to make a better decision, learn more and be more efficient in his functions. Such improvement includes operational, managerial and decision making with the provision of information/knowledge.[63] [64]

The range of tools and systems supporting OM is untold. Shortly citing some examples, one can mention document management systems, decision support systems (DSS), e-mail, information repositories, artificial intelligence (AI), modelling, and so further. Naturally, everything involving Building Information Modelling (BIM) technology will also be intrinsically connected within IS, OM and hence OMS, leveraging and significantly improving the organizational evolutionary process. Any information system within this platform will be dealing with the acquisition and storage of building's information, holding every constructive feature necessary for the execution and management of construction projects.[65]

According to Stein and Zwass (1995) and their constructed framework, OMIS consists of two different layers of operation. The first is subdivided into four sub-processes: (i) *Integrative Subsystem,* supporting the organization employing sharing the knowledge through all its levels; (ii) *Adaptive Subsystem*, adapting the acquisition, retention and retrieval of knowledge within the organizational environment to the environmental changes throughout time; (iii) *Goal Attainment Subsystem*, which apart from the base processes of OM, it aims precisely to the achievement of organizational performance goals; (iv) *Pattern Maintenance Subsystem,* relating to the organization's morale and is therefore constituted by knowledge rooted in attitudes, values, standards and routines.[66]

The second layer is recalled by Mnemonic Functions and corresponds to the process elucidated in the previous section of organizational memory concerning the acquisition, retention, and sharing of knowledge. Stein and Zwass (1995) added to it the maintenance and research processes, referring respectively to the capacity of assimilation of the systems in terms of new knowledge and the agility and reliability with which the

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[63] Zhang 2013.
[64] KMT 2018.
[65] Barros, et al. 2015.
[66] Stein & Zwass (1995).

information systems enable the search processes in the search for internal information and therefore for its dissemination.[67]

Nevertheless, organizational memory information systems will contribute intensively to increase organizational performance and productivity, retaining large proportions of knowledge, thereby supporting its processes of creation and dissemination. Its effectiveness will reflect the facilitated achievement of an organization's objectives and its competitive advantage. Therefore, OMIS play's role becomes important, adding knowledge management power to entities and enabling a unique environment of constant knowledge flow amidst individuals inserted within it. The challenge remains to select the most appropriate system for the organisation and compatible with its processes and internal environment, which would retain advantageous knowledge for reliable and safe reuse.[68]

3.3.3 SECI Model and Knowledge Conversion

Within the organization knowledge field is the imperative SECI Model, proposed and created by the renowned Ikujiro Nonaka. The acronym SECI stands for the words *socialization, externalization, combination and internalization*[69]*.* Brought up during the 90’s decade by its former, the model sought to explain knowledge creation based on extensive studies of explicit and tacit knowledge. The idea winded up being positively disseminated among knowledge management and organizational knowledge, adding high recognition to the subject. Consequently, the model became a cornerstone of creational knowledge and transfer theory, contributing to the recognition of Nonaka within the field.[70]

The structure grants knowledge creation as a dynamic process hinged on the two outlined types of knowledge already described – explicit and tacit –, establishing a spiral clockwise development as depicted by the figure below. Such systemic and ongoing process differs from most known knowledge management tools, which are mainly proposed on an evolutionary path – therefore a straight (not cyclical) form of development[71]. The adopted design covers distinct ontological levels regarded as the

[67] Stein & Zwass (1995).
[68] Barros, et al. 2015.
[69] Dubberly and Evenson 2011.
[70] KMT 2018.
[71] Farnese et al. 2019.

individual, organizational and inter-organizational. They provide a spectrum for generating knowledge from the inside-out of the company and are not only based intrinsically on external sources for its build-up.[72]

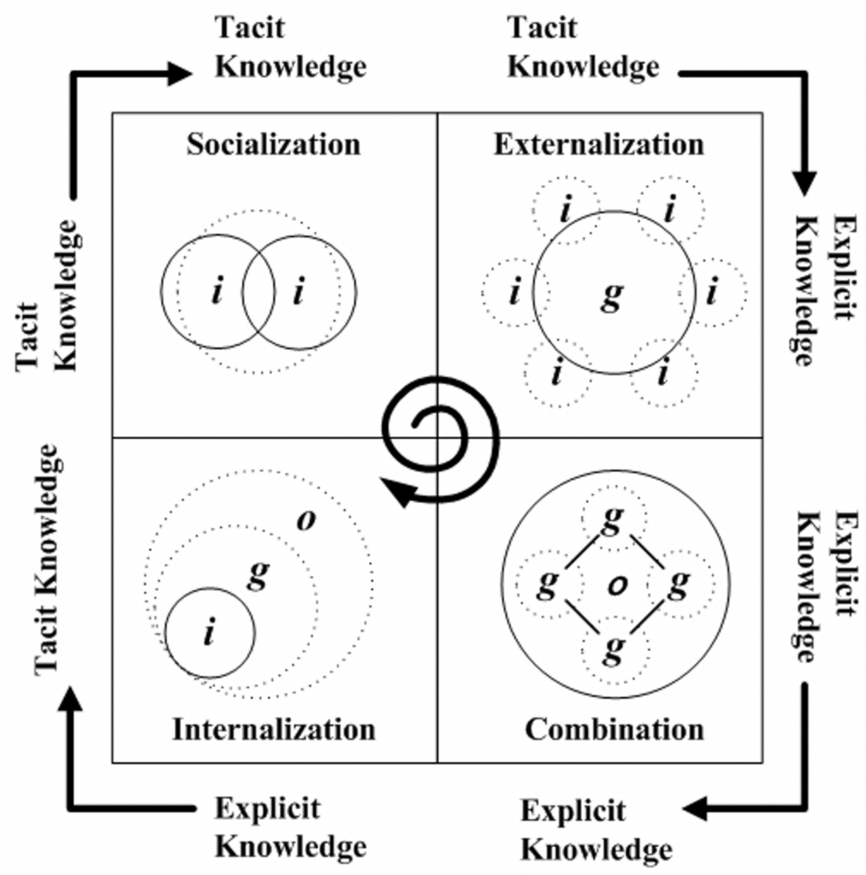

Figure 3: Knowledge Creation as the Self-Transcending Process[73]

As proposed by Nonaka and Takeuchi in the early year of 1996, the diagram is endowed of three different classes represented by the letters *"I", "g"* and *"o",* which respectively stand for *"individual", "group"* and *"organization"*. Those patterns interact with each other, generating different relationships and, therefore, knowledge. Such relationships occur between elements of the same classification (e.g., tacit to tacit) from different ones (e.g., tacit to explicit and vice versa). Each correlation represents one of the knowledge generators standing for the acronym SECI, further broken down.[74]

[72] Dubberly and Evenson 2011.
[73] Nonaka and Konno 1998, p.43.
[74] Nonaka and Konno 1998.

Socialization

As the term already indicates, it corresponds to sharing tacit knowledge between two or more individuals. Socialization, as we well know, may be related to a whole range of daily activities experienced by each of us and the sharing of information during a walk at the park, sharing the same physical space, and so on. Throughout those daily exercises, a considerable amount of personal information and, therefore, knowledge is switched from one individual to another.[75]

Thus, *socialization* is highly dependent on how prone one is to listen and learn from a second perspective. Shortly exemplifying, long years of experience in a particular field enable newbies to understand better and feel what awaits them ahead. Therefore, the quality and amount of knowledge to be captured will rely individually on abstracting the information flow around. The more present and attentive an individual can be, the more he will be adding to himself, from interactions among colleagues and customers or simply by walking around assimilating how things are. At the same time, the dissemination of tacit knowledge is another critical aspect of its success. Hence the didactics upon expressing one's experience and ideas to others significantly affect socialization and its embedded learning.[76]

Externalization

Externalization is characterized by forming a group of individuals to share and discuss tacit knowledge, which will be translated into comprehensible forms of explicit knowledge, thus enabling its dissemination and understanding by others. Externalization occurs from gathering personal and singular individuals' knowledge into one idea and intention, represented by committing the individuals to the group. The result is a single agreement from all these parties and, therefore, a single and concrete art of knowledge. Techniques as long dialogues solidly support the externalization of thoughts, concepts and etcetera.[77]

At this point, it is clear to understand the idea behind externalization, but the formalization of translating the tacit knowledge of a group into readily understandable forms is a significant aspect. The conversion process will mean a lot to the accessibility and

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[75] Nonaka and Konno 1998.
[76] Nonaka and Konno 1998.
[77] Nonaka and Konno 1998.

ease with which a third party will be facing such “new knowledge” and is a milestone for the success of externalization. Form and contextualization play a significant role in this sub-process and the whole practice within the SECI model and its translation.[78]

By analysing the case study brought by this paper, externalization becomes clear among the contribution of several professionals to a single project. By utilizing an information system and a database, most tacit knowledge becomes explicit byways of dialogues, flaws, corrections, and solutions for the project. The depiction of such is clarified by the chapters regarding the methodology construction of this research.

Combination

In combination, again, the knowledge responsible for the creation is the same which is generated. Explicit knowledge is converted into more complex and systematic explicit knowledge, emerging from combined inside and outside knowledge of a company. Ideas from various groups interconnected within organizational interests contribute to the birth of new knowledge, which is thereafter disseminated among the members of the same institution.[79]

According to Nonaka and Konno, the combination phases follow three processes. First comes the capturing and collecting of internal/external data. Secondly is the dissemination of such data within the company through, for instance, the provision of presentations or arrangement of meetings, making sure that knowledge is spread among all necessary corners of the company. Lastly, the editing phase takes place and provides usability for the whole process (e.g., documentation, reporting). Combination constitutes an important step upon concrete decision-making within an organization and holds a high responsibility for that.[80]

Internalization

Internalization is the only process that acts directly connecting the *individual, group* and *organization* prospects. It represents the conversion of known, formal, explicit knowledge into the unformal tacit one. One individual in possession of existing explicit knowledge created and shared from within an organization generates a relevant

[78] Nonaka and Konno 1998.
[79] Nonaka and Konno 1998.
[80] Nonaka and Konno 1998.

fraction of tacit knowledge throughout the time due to long periods of practices and self-development. Again, as prior, it requires finding oneself with awareness to absorbs available knowledge provided within a large entity – which materialize from, e.g., learning-by-doing, exercises and training.[81]

Two dimensions compose the process of internalization. First, explicit knowledge must be incorporated into action and practice, enabling the company's internal process to be updated and improved to meet the demand for knowledge and expected results when later shared. Corporate training depicts this first dimension well, where trainees are exposed to essential information that helps them understand the entity throughout the process. The second dimension, which each year proves to be increasingly more prominent and takes part in a more significant portion of this matter, embodies the explicit knowledge using technology, be it from virtual simulations or experiments to trigger learning by doing processes.[82]

In rundown, the SECI model provides a dynamic process of exchange and transformation of learning. Explicit and tacit knowledge correlates among the four proposed modes of knowledge creation, producing a conceptualized updating of knowledge within social entities. This ongoing process ensures the generation of continuous new knowledge in a field that never stops moving forward.[83]

In recent years, the model's applicability, instead of being overtaken by other new methods, is becoming even more rewarded among knowledge creation, strongly linked to organizational and national cultures. Notwithstanding decades of its creation, the SECI model and its founders still hold prestige at the core of knowledge conversion theory within KM, indicating solid signs that its aspects universally appeal to most cultures.[84]

3.4 Knowledge Management within the AEC Industry

Following the excellent recognition knowledge management would hold upon reflecting improvements in other related fields, the AEC industry also adopted the ideology in its earlier years of birth. Despite slower development before the 1990s, the

[81] Nonaka and Konno 1998.
[82] Nonaka and Konno 1998.
[83] Nonaka and Konno 1998.
[84] Andreeva & Ikhilchik 2010.

implementation of KM within the field followed an evolutionary path like that of KM in general, evolving significantly alongside the adoption and development of IT in the construction industry.[85]

AEC area is famously recognized as being a knowledge-intensive industry relying on information from several fields of activity. Hence, it accumulates vast amounts of knowledge and data for each specific project, whether explicit and documented in papers, databases, manuals and so on or tacit and kept within its various professionals accumulating years of experience and personal knowledge, which within this field is even harder to formalise and manage compared to others. As a result, many new methods and IT applications concerning the use of KM and AEC have arisen in the past period, creating mechanisms able to store and share such intensive daily knowledge besides contributing to the creation of fresh new methods.[86]

That said, the knowledge generated throughout the lifecycle of a project is markedly vital for enhancing the industry, ranking as one of the most critical assets of AEC and encouraging innovative processes to overcome unique project-specific challenges and achieve higher performance[87]. For a firm, storing and sharing explicit and tacit knowledge among the design and execution of projects means a substantial reduction of costs and time whilst being decisive for its competitiveness and survival within the market.[88]

The decentralized spectrum of the AEC industry means that KM implementation is not practical for all projects, requiring further analysis before its adoption[89]. Typically, when a large project is in the planning stage, several third-party companies responsible for different factors are involved. Such companies arrive with their knowledge background focused on a specific objective aimed to their goals, carrying them out without having a genuine interaction on the general knowledge of the work between other parties involved and therefore restricting the flow of specific knowledge between certain sectors and individuals, which in itself reflects into knowledge being scattered across project teams.[90]

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[85] Kuo 2019.
[86] Designing Buildings Wiki 2021 (3).
[87] Designing Buildings Wiki 2021 (3).
[88] Tserng and Yu-Cheng 2004.
[89] Designing Buildings Wiki 2021 (3).
[90] Fong 2005.

Thence, the loss of knowledge reflecting repetitive flaws causes severe damages to the industry. The British Standard Institution (BSI), in an article published in 2003, suggested that such a vicious cycle of the inefficient use and communication of information costs at least £20 billion per year in the UK construction industry to be overcome through repair or rebuild processes. Nevertheless, today's numbers of companies embracing knowledge management applications are still relatively small and roughly comparable to the levels reached 18 years ago.[91]

Like any other field, construction faces the same major obstacle to KM: capturing tacit knowledge. Kuo (2019) stated that besides sharing know-how knowledge involving face-to-face contact, virtual interaction plays a significant role[92]. Therefore, tacit knowledge and its capturing solutions have become the main objective of this research. Taking advantage of the ease with which digital evolution is bringing to the industry, proposes to overcome this barrier by using intelligent applications within a BIM methodology. In this sense, stands out the real-life communication proposed for a few available applications, based on a database and a BCF format, storing through the flow of information between parties an outstanding source of knowledge.

[91] Designing Buildings Wiki 2021 (3).
[92] Kuo 2019.

4. Information Management

Nowadays, the BIM methodology is the most outstanding example of how to facilitate and execute information management in the AEC area and, therefore, the subject deserved to be portrayed in this article. Additionally, going deeper into the meanings of IM, the comparison with knowledge management is relevant to understand its differences and even more if a process is managing information or knowledge or when the management of one can later be transformed into the other.

Information Management, as intelligently coined out by Choo (1995, p. 81), *"is a cycle of processes that support the organization's learning activities: identifying information needs, acquiring information, organizing and storing information, developing information products and services, distributing information, and using information".*[93]

In addition to this early description, Wilson (2002) noted that the term was often inconclusive in the literature. Computer science archives would infer it as a synonym for information technology management – is closely related to data management –, highlighting its technical development. In contrast, business or management documents would substantiate its relation to business performance and competitiveness.[94]

Efficient management means building an efficient strategy of creating and allocating information within the boundaries of an organization aiming to achieve its goals. Thence, information must be efficaciously accessible for groups and individuals who will use it to master their works and foster themselves. According to Choo (n.d.), in order for the organizational processes to make greater sense and produce significant results, a view of information management bound in a continuous cycle of six firmly related activities is advisable. They encompass:

- *"Identification of information needs*
- *Acquisition and creation of information*
- *Analysis and interpretation of information*
- *Organization and storage of information*
- *Information access and dissemination*
- *Information use"*[95]

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[93] Choo 1995, p. 81.
[94] Wilson 2002.
[95] Choo n.d., n.p.

The closed cycle depicts shortly how the IM process is performed and mastered. The idea underlying IM is that an organization purposefully and systematically utilizes the information as any other current asset it holds, meaning that information resources and processes should have the same management attention as, for instance, facility management. Thereby classical functions such as goal setting, training staff and assessment apply to the same level of importance for IM as any other significant managerial activity.[96]

However, strategy information, disregarding fields, will always be correlated to achieving the most critical organization's goals. Its direction will always focus on aligning its objectives and ideas with those of an entity and those responsible for it, contemplating consistently the same final vision. Established upon this ideal, frameworks incorporating desirable organizational results articulate the lineage for developing information, whether consisting of one or more strategic focus areas, thus easing critical decision-making.[97]

Independently on the view, information management attracts countless benefits to a company. Based on its principle, it has always been listed as a source for cost reduction, significantly decreasing the uncertainty and risks and adding value to existing products and services and creating new values of information-based for both[98]. Accompanying the development of technology and, therefore, creating increasingly sophisticated information management systems, the benefits of the matter continue to grow in parallel with its evolution. Thence, this paper investigates shortly the role of IT in information management and how it has become an integral part of all existing business today, providing power, versatility, and ease in supporting information handling.

4.1 Information Systems and Management Information Systems

Both information systems (IS) and management information systems (MIS) rely directly on information technology (IT) for their operation, which in turn is expected to be an elementary part of any development of an information management plan. Thence, a

[96] Choo 1995.
[97] Choo n.d.
[98] Choo n.d.

sub-introduction to the meanings and roles of IT is made necessary for the comprehension of the matters.[99]

Information technology is commonly coined out as any computer-based tool used by individuals whose primary role is to build a technical infrastructure that eases the processing and motion information supporting either personal or organizational processing needs[100]. Therefore IT infrastructures grant its users reliable and responsive access to several services (e.g., applications and databases), improving organizational performance[101]. Its tools and platforms are becoming increasingly sophisticated and indispensable to individuals, corporations, and the planet itself.

Information systems definition is among the literature commonly regarded as networks or combinations of hardware and software design to collect, create, process, and distribute valuable data in organizational settings supporting decision-making, coordination, analysis, and control[102]. Nowadays, to make use of IS is to be making part of the connected generation in which we find ourselves. Technology is so ingrained in our lives that it is negligible to think about running a company without using it, assuming that all organizations will undoubtedly undergo a digital transformation if not up to now.[103]

Due to the exponential growth of IS and IT in the 1970s, the study of management information systems (MIS) focused on computer-based information systems. MIS combined the mutual work of two approaches, the technical and behavioural. The first was developed to provide solutions to the real-time difficulties faced by companies and manage information technology resources. Technical approach endowed the essential fields of computer science, management science and operations research. However, the behavioural approach was concerned with no fewer majors such as the sociological, economic, and psychological, studying the impact of developing information systems in human behaviours[104]. The outcome is a thorough discipline that has been influencing other disciplines about information processing development.[105]

[99] Rainer, et al. 2020.
[100] Rainer, et al. 2020.
[101] Choo n.d.
[102] Bourgeois, et al. 2019.
[103] Rainer, et al. 2020.
[104] Azimuth Interactive Inc. 2006.
[105] Baskerville & Myers 2002.

The management information systems department ensures that the entire network is functioning at an optimal level of use, providing users with what is seen and manipulated on their computers. MIS is a highly complex and challenging task involving costly information systems from acquisition to maintenance. Furthermore, the massive use of MIS within organizations creates a kind of "dependency", meaning that, if these systems are not working, the company, consequently, will not be in operation either – commonly coined out as “being hostage to information systems”.[106]

MIS operations are composed of two ends, the user and the MIS department. Both hold different responsibilities for maintaining and developing IS, differing amongst organizations based upon several internal factors like size and field of action. Typically, this subdivision would occur between the former being responsible for departmental resources, while the latter responds for macro / corporate-level and shared resources. Nevertheless, MIS is essential because both users and departments work in close cooperation for the well-functioning of the systems and company. For instance, the responsibility of the MIS department is to oversee general maintenance and troubleshooting of IS so that the user (seen almost as a customer by the department) can enjoy the smooth operation of the system.[107]

4.2 Types of Information Systems

Information systems are spread out among different types of systems and applications. Due to consistent different interests and organizational levels present in an entity, requiring different systems to support each one of them. No single system can provide all the necessary information one organization needs. The result is a range of systems working in cooperation and at different organizational levels to achieve individual and collective goals of the same corporation.[108] [109]

Although the range of information systems is manifold, Azimuth Interactive (2006) subdivided IS into four different major types of systems among three categories serving different organizational levels as depicted by the pyramid below.

[106] Rainer, et al. 2020.
[107] Rainer, et al. 2020.
[108] Anthony 1965.
[109] Azimuth Interactive Inc. 2006.

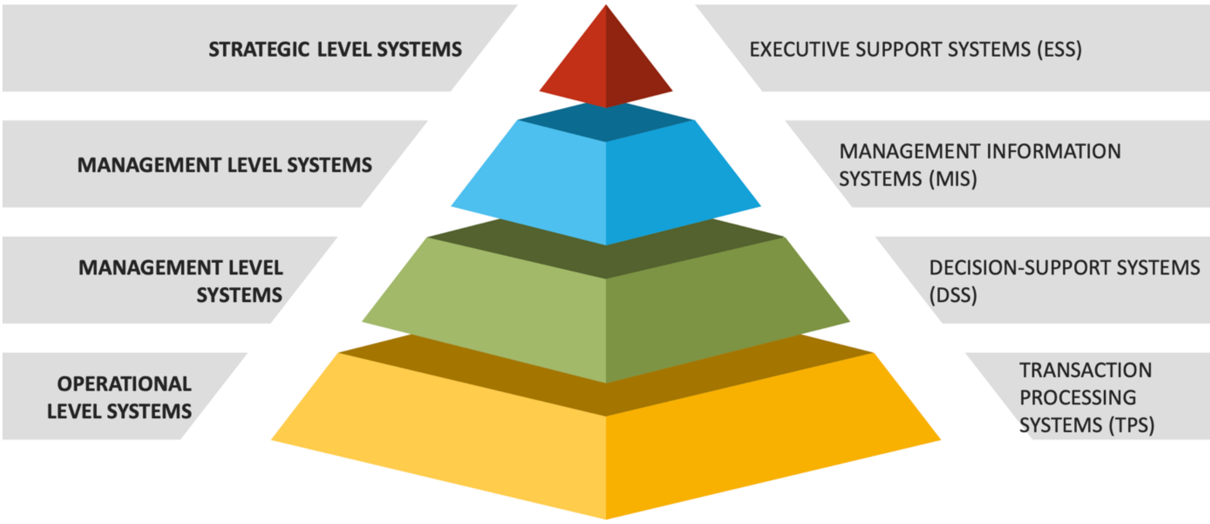

Figure 4: The Four Major Types of Information Systems[110]

The levels are represented by the operational-level systems, management-level systems, and strategic-level systems, structured accordingly to their degree of influence within the organization. The workability and supportability of these systems are depicted right below, offering concise information on how they encourage a company's performance.

Transaction Processing Systems (TPS) are elementary business systems that process the company's business activities while supporting the organization's operational level. All transactions are processed and stored within the company's database by computerized systems, thus creating a daily report of all the routine transactions necessary to conduct the business. Thence, all activities are rightly documented according to the company's predeterminations. Examples of transactions are sales orders, merchandise control and employee record keeping.[111] [112]

TPS is divided into two types: *batch transaction processing*, which is the information that is collected and stored but not processed immediately and *real-time transaction processing* (or simply *online transaction processing)* which provides the user with immediate processing information linked to direct access to an online database.[113] Online

[110] Adapted from Azimuth Interactive Inc. 2006.
[111] Joshi n.d.
[112] Azimuth Interactive Inc. 2006.
[113] Amin et.al 2012.

Analytical Processing (OLAP) belongs to the latter, and it is the most common mode in use today for transactions processing.[114]

Nevertheless, practically any organization relies upon TPS to oversight business nowadays. Positioned at the bottom and responding to all the foundational activities, TPS is the primary producer of information supplying the hierarchical model of systems and therefore of extreme importance for the whole chain, meaning that managers demand TPS for internal operations control and external relationships analyses with other firms. Its temporary failure may lead to enormous internal and external/environmental damages, which, in extreme cases, can even become irreparable.[115]

Although the type of system regarded as *Design and Production Systems* is not among the essential systems by various authors, it deserves to be mentioned here respecting its direct value with the theme of this paper, which includes a prominent design role linked to BIM use technology. Computer-aided design (CAD) software has been present in the construction field for years and takes on much technological evolution. It has allowed architects, designers, and engineers to digitally produce computer models before moving on to execution plans and representing a significant type in construction.[116]

At the management level systems, one is faced by the only organizational level where two major IS types can be found: the **Management Information Systems (MIS)** and the **Decision Support Systems (DSS)**. Although the term MIS and its significant emphasis as the study of information systems in business and management were introduced earlier in this article, it carries a different meaning and action related to management levels. MIS, in this context, labels a specific category of information systems applied to management level functions.[117]

MIS is almost exclusively concerned with managing internal sources of information at organisational levels, leaving out environmental or external events. MIS, retrieving data that most often depends on the underlying TPS, provides managers with summaries, which result in a series of periodic reports and broad online access to the organization's operations and performance. The needs of each manager will define the type and form

[114] Joshi n.d.
[115] Azimuth Interactive Inc. 2006.
[116] Creative Commons 2012.
[117] Azimuth Interactive Inc. 2006.

of the reports, varying between different perspectives within a company and containing only valuable data to support specific decision making, supervise activities and solve problems. A great example to be highlighted within MIS is the use of key performance indicators (KPIs) to assist managers in supervising the fulfilment of activities and tracking the company's progress towards achieving its primary development goals.[118] [119]

As well as MIS, the decision-support system (DSS) will also serve to the management level of the organization. The term refers to interactive computerized systems consisting of hardware, software, data, and models design to assist managers in decision-making.[120] It provides an answer for unexpected issues arising within a company, turning into unique and rapidly changing solutions which are not easily specified in advance. DSS is based on a wide range of sources and, rather than MIS, is often concerned about external sources of data, such as market price or industry data. TPS and MIS provide the internal information necessary for DSS analytical processes.[121]

Therefore, the central role of DSS is to gather and analyse relevant information, making use of complex spreadsheets and internal databases, condensing a large amount of data into models which can be easily interpreted and used for decision support by individuals. As Beal (n.d.) highlights, it is a process that resembles the action of artificial intelligence agents greatly and therefore is also common to assimilate DSS as business intelligence systems. Hence, it becomes clear that the analytical power of DSS is beyond the other information systems.[122]

Above all, DSS also works with a simple, flexible, and practical interface that allows users to understand the software thoroughly and allow the user to modify and include data when necessary efficiently, being the milestone of such a system. It means that any senior manager, for instance, who has little or no experience with computerized systems, will understand what is being processed on the screen and take their decisions. Therefore, one can argue that the DSS key performance is how well it meets the user needs, aiming to be as informative and as user-friendly as possible.[123] [124]

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[118] Azimuth Interactive Inc. 2006.
[119] Creative Commons 2012.
[120] Gregg Learning 2020.
[121] Azimuth Interactive Inc. 2006.
[122] Azimuth Interactive Inc. 2006.
[123] Gregg Learning 2020.
[124] Azimuth Interactive Inc. 2006.

Now, when the operational and the management level systems are already shortly explained, it comes the time for reaching the pike of the organizational pyramid and introduce the last major information systems regarded as **Executive Support System (ESS)** – also known as Executive Information System (EIS). ESS serves intrinsically to the organisation's strategic level and therefore to the senior managers, enhancing their decision-making. Unlikely the previous information systems depicted in this paper, ESS is not designed to majorly act as a problem solving and is not as profoundly analytical as DSS. Instead, ESS provides a broader communication capacity to CEOs, requiring their evaluation and insight to arrive at a final solution. In other words, the system's information and the experiential knowledge held by managers result in the final decision.[125] [126]

ESS is designed to incorporate data from external and internal resources, gathering, analysing, and summarizing only critical business information into quickly accessible and strategic-level reports. According to its aim, the summarized internal information is obtained from the MIS and the DSS, while the external information varies from various events. The systems filter, compress and track strategic information, providing CEOs with only the most relevant information, avoiding such overloading. The information gets to them frequently through a portal using a web interface or internal applications. Furthermore, ESS engage the most sophisticated graphics software while employing easy-to-use interfaces, thus generating high-level graphics and data from various sources.[127]

Along with the previously explained information systems, there are still a series of others supporting either the same organizational levels or simply designed to support the organization's employees - systems that boost *clerical workers, lower-level managers* and *middle* managers to perform and enhance their daily activities. Two of the most found practices are **Business Analytics Systems (BA)** and **Dashboards** (also called digital dashboards).[128]

BA systems are also known as business intelligence systems (BI) and, through a computer-based structure, they support middle managers, knowledge workers and lower-level managers (this last in extent). Simply put, the system runs through a data

[125] Azimuth Interactive Inc. 2006.
[126] Techopedia 2012.
[127] Azimuth Interactive Inc. 2006.
[128] Rainer, et al. 2020.

warehouse which allows users to perform instant analysis of their desired data. Dashboards, on the other hand, are specialised for all management levels from an organization. They concern every operative level of management, providing structured "progress reports" linked to a database promptly within instant access.[129]

Dashboards grant its user an "easy to read" real-time interface, represented by graphics of the status of organizational activities or key performance indicators (KPI's). The analysis of those graphs eases greatly managers instant decisions, becoming an exponentially growing tool in the market.[130] In this sense, they will represent a significant part of the synthesised information resulting from the analyses of this proposed case study, easing thus the perception of information arriving at the executives and creating knowledge regarding the project constraints.

4.3 Information Management vs Knowledge Management

Although the comparison and misunderstanding concerning the differences between information management and knowledge management have been present for a long time in the field, both subjects are still misused mainly by a vast number of people. Mostly, the situation occurs due to their closeness and their interrelationship. Their understanding and correct definition are of high importance when analysing how to proceed with their management. Thus, as an initial effort in this regard, the previous definitions of data, information and knowledge offer a vital awareness of their distinctions - although not characterizing their differences so profoundly - and serve as introductory to this discussion. Besides, a more detailed explanation of the two is essential to avoid mistakes and misunderstandings.[131]

First, the core of KM, tacit knowledge, is commonly overlooked. While KM takes into high relevance the so-called "human element", IM focus has been consistently related to manipulating data and information. The way people learn, develop, and share knowledge is KM's strict responsibility[132]. The gap constitutes the most common flaw in differentiating both types of management. Therefore, a mere misconception is that documents simply containing information or related to management systems are to be

[129] Rainer, et al. 2020.
[130] Sutner 2020.
[131] KMT 2018.
[132] Terra & Angeloni 2003.

considered KM solutions, which, clearly by now, is a flaw[133]. Figure 5 below raises five main characteristics of each of them, easing their identifications and avoiding their interchangeable use.

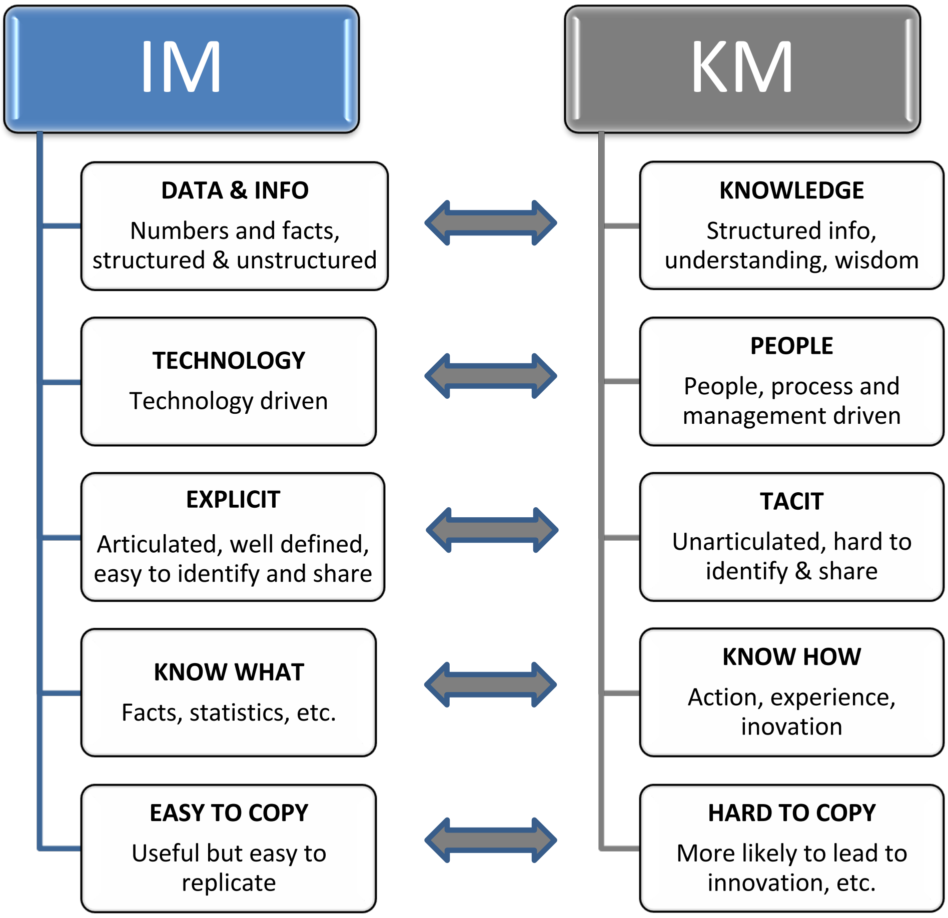

Figure 5: Information Management vs Knowledge Management[134]

After analysing the figure above is prudent to affirm that hardly one will mistake the definition of IM to KM, but quickly the other way around. Due to the higher complexity of defining knowledge in comparison with information, the fact is a consequence of the critical role played by human beings in the first. Thus, KM utilizes the information creating the right conditions for the individual to learn and grow, directly benefiting the organization development with the creation of knowledge. The same can anew be transformed in information and hence be shared and reused widely for the company's

[133] KMT 2018.
[134] Adapted from KMT 2018.

benefits. The process is firmly based on the “spiral of knowledge creation” explained previously in this paper.[135]

Fostering the distinction is the difference in measuring results concerning IM and KM. The results associated with information management are intrinsically based on quantitative outputs, following the long tradition of information technology projects. Contrastingly, knowledge management requires a different approach, which again is due to the individual's behaviour. Individuals’ willingness to share their knowledge with others or with the organization itself is the only way of measuring its results. Thus, as long as a being keeps knowledge within himself, its distribution, coding and use for the empowerment of organizational systems become inconceivable.[136]

Finally, KM will be more closely related to the “act of managing”, coined out as a never-ending cycle of interrelation between individuals and individuals with information systems, the core relationship element of this research. Therefore, knowledge management is – especially today – entirely dependent on information systems and IT infrastructure to support its development and its evolution throughout the future years. However, never forgetting its value-driven behaviour. This requires a strong co-working sense among knowledge-workers and information-workers – although they might never meet personally. Although IM solutions are distinct from KM, they are key enablers of knowledge creation and sharing and accelerators towards the field's evolution.[137]

[135] Terra & Angeloni 2003.
[136] Terra & Angeloni 2003.
[137] Terra & Angeloni 2003.

5. Building Information Modelling

The construction field, like most other industries, has evolved a lot technologically and digitally constantly over the past few years. Especially within the last 20 years - more or less the time when I started to walk around construction sites -, the creation of new technologies, as well as the evolution of existing ones, has revolutionized the construction field and its market, causing a mindset turnaround of how companies and people think about its execution and management. In this sense, a diverse range of modern tools and methods have been generating countless positive results.

To this extent, Building Information Modelling (BIM) has assumed greater responsibility and has become the primary turning key within construction management. The method is a concept dating back to the early 1970s and is likewise the first software tool developed for modelling construction projects and information gatherers.[138]

However, the term and its ideas would just become well known decades later. The first hardware necessary to run such innovative applications was either too expensive or too big and robust to be used worldwide and by a significant number of individuals, which negatively impacted the platform's evolutionary pace[139]. Hence, among the development of better hardware and applications, amid the early 2000s, BIM stood out in the field and companies and experts began to give it greater recognition[140].

BIM as an acronym stands for Building Information Modelling or Building Information Management. The latter is commonly used when the platform stretch over the operation and management of buildings, where owners are granted exclusive access to it and its structures to refine their decisions during and after project execution. At its core, though, BIM, an extensive term, is a highly collaborative platform for construction professionals, companies, and government agencies to plan, design, and construct diverse physical infrastructures within the same 3D model simultaneously. Hence, its most common cases include drawing generation, progress monitoring, design coordination, quantity take-off, visualization, and facility management.[141] [142]

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[138] Eastman, et al. 2008.
[139] Eastman, et al. 2008.
[140] Leite 2020.
[141] Borrmann et al. 2018.
[142] Lorek 2021.

BIM most valuable asset is thus the management of all the information being entered by all the parties and individuals arising from different disciplines involved within all the levels of a project lifecycle, working collaboratively and sharing large amounts of data which, beyond being stored, are also focused on necessary actions and decision making.[143]

As a result of this range of information, a *federated model* emerges, resulting from the effective collaboration of its major stakeholders. The actual creation of such a model is based on the use of a deep variety of different software applications directed to the implementation of different uses cases (i.e., architectural, structural, and plumbing). Thence, BIM must be comprehended as an information management method and not a single software or system.[144]

Access to such information occurs via an online network and can be done everywhere through a mutually space known as a *common data environment* (CDE). Data stored at CDE is frequently referred to as an 'information model', which can be used throughout all stages of a building's lifetime.[145] Both the federated model and the common data environment are better explained as follows.

5.1 CDE and Federated Model

The common data environment was for the first time authored by Mervyn Richards back in 2007 and thus far has been directly representing the process of BIM storage systems. CDE is a cloud-based space housing all the information conceived from a project within a single source. It collects, manages, and disseminates information in documentation, graphic models, and non-graphic data for the professionals and owners involved. The data, it is important to note, accrue whether from an asset created within a "BIM environment" or conventional data format content, thus providing a broader perspective of the project information.[146] [147]

The reason for creating a single source of information was to ease collaboration and teamwork between members, besides avoiding duplication and minimizing errors.

[143] Borrmann et al. 2018.
[144] Borrmann et al. 2018.
[145] Lorek 2021.
[146] McPartland 2016.
[147] Designing Buildings Wiki 2021 (2).

Therefore, the idea of cooperation to boost the effectiveness of a project's results is granted to the use of the CDE by several organizations and construction professionals. In consequence, many BIM protocols, regardless of their country of operation, propose the appointment of an 'information manager' who is substantially focused on keeping information synchronized and coherent – i.e., an individual with no responsibility for the project and other intended tasks of, for instance, a BIM coordinator. Information managers have a second primary responsibility within this process, that of easing management and ensuring that the BIM protocol procedures of the so-called 'federated model' (also defined as a 'combined model') are being followed, which results in a secure data storage.[148]

Nevertheless, unlike the second level of BIM - which treats each model and discipline individually -, in the third level of BIM maturation (Level 2), models from a variety of construction disciplines are uploaded into the CDE database, where they are combined into specific software to form a single, complete piece. The result is coined as the federated model, which forms a single model constituted of different designs. It is the first appearance of the CDE, showing all its power, use within the methodology.[149]

Stakeholders are simultaneously working on the same shared model while preserving the integrity and identity of independent designs, which means that modifying a single design will not generate additional modifications to another component model. That said, the responsibility of each project remains the same throughout the entire process, regardless of whether they are linked to a federated model or not, meaning clear and independent authorship of them.[150]

The benefits of having a federated model are manifold. The simple idea of enabling the visualization of several models in one tool should be by itself sufficient. However, advancing in the range of improvements that an organization favours, there can be still highlighted some other significant enhancements as:[151]

- Enhancement of coordination and design development
- Improved estimations
- Faster and easier approval processes

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[148] McPartland 2016.
[149] McPartland 2017.
[150] Designing Buildings Wiki 2020 (2).
[151] McPartland 2017.

- Enhanced estimations and improved clash detection and avoidance[152]

Such aids reflect, alongside the greater collaboration and joint work among diverse entities, in a more concrete and well-defined project producing greater agility and costs reduction. Notwithstanding, the liability and copyright issues arising from changes in interoperability and collaboration between the transition from the second to the third maturity level of BIM can increase substantially, thereby growing the hardship of re-solving them. An excellent solution for this is based on the adequate management of information, which can essentially minimize such undesirable results.[153]

Regardless of the interoperability between models drawn on to produce the federated model, the ownership of information stored in the CDE always belongs to the different original contributors - reflecting design teams and individual projects -, holding, therefore, absolute control of their data. Access to information is only possible when granted by these contributors, usually directed at clients, but can also be addressed to other participants and team members. Licenses hold different authorisation levels, depending upon the purpose for which the level of detail of information is intended, releasing only the necessary amount of information for the 'permitted purpose'. In turn, clients can then issue a sub-license allowing project team members from different design areas to access models built by other contributors according to their requirements.[154] [155] [156]

Information within the CDE can contain an immense variety of status levels, flowing from one area to another according to sign-off processes allowing its transaction. This information movement creates a structure to be followed, which, in the case of BIM designs, consists of four primary areas of information, briefly described as:[157]

- *Work in progress (WIP):* it holds unapproved individual information generated from different design providers
- *Shared area*: the area where all information is checked, reviewed, and approved before further dissemination among clients and stakeholders

[152] Designing Buildings Wiki 2020 (2).
[153] Designing Buildings Wiki 2020 (2).
[154] Designing Buildings Wiki 2020 (2).
[155] McPartland 2016.
[156] Designing Buildings Wiki 2021 (2).
[157] Designing Buildings Wiki 2021 (1).

- *Published*: information is therefore authorized either by the clients or their representatives
- *Archive:* area holding a constant record of the entire information progress, as well as of any transactions and modifications effectuated during the life cycle of a project[158]

Hence, a common data environment provides a stable platform for all information to be recorded, distributed, and resolved at a low cost and high benefit, resulting in efficient deliveries, greater collaboration and a well-informed customer and stakeholders. Construction professionals rely on this bridge between the CDE and BIM methodology to increase their control power and provide more valuable and faster execution designs, serving as a solid foundation for the construction industry's digital transformation. The result is a strengthened project employing technologies and processes providing a high level of information, thus eliminating several flaws commonly found when following old procedures.[159]

5.2 BIM Maturation Levels

Developed by the UK Task Group, the BIM Maturity Model represents four different levels - ranging from 0 to 3 - of BIM Implementation, depicting the different levels of shared collaboration in a project. In a piecemeal way, its primary goal is to ease the construction industry’s transactional processes to become based on entirely digitized models. Such processes are new technologies and hence the new procedures to be followed for their perfect execution and highest collaboration.[160]

BIM *Level 0* is the rawest stage of maturity, describing a project with null collaboration among its members based on 2D CAD designs and elevated amounts of paper-based documents. Despite an electronic flow of information, it does not follow any procedures or common standards and protocols. Although the use of BIM-oriented software projects offers no communication between one another and, although occupying the lowest position of maturity, technicians still vastly use this level.[161]

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[158] Designing Buildings Wiki 2021 (1).
[159] Designing Buildings Wiki 2021 (1).
[160] Borrmann et al. 2018.
[161] BibLus n.d.

Partial collaboration and visualization, and concept development models can be perceived for the first time at *Level 1*. Its focus is recognized in the changeover of CAD information to 2D and 3D models, whilst most projects are still carried out in 2D drawings. Besides, the CDE enters the scene and starts to be used for data collection and storage. However, it only offers such usages without really allowing access between the different actors - no federated model that results only in information management. Given the absence of a central project platform, the only ways to exchange information are by sending and receiving files from different project team members.[162] [163]

Level 2 represents the full integration of BIM while expanding and strengthening the subject's use within the construction industry. The information is now built onto a unified federated model shared among project stakeholders, thus enabling collaboration amidst different designs and teams. The distribution and storage of shared information occur using standard file formats, such as IFC, commonly used to exchange BIM data. Standardizing ensures the enhancement of collaboration and data management, albeit facilitating access to information among all sources of knowledge, disregarding the use of miscellaneous software to develop their models.[164]

As with Maturity Level 1, data management and recording depend on the responsibility and use of the CDE as a central data storage facility. Throughout this process, periodic coordination sessions are indicated, undergoing clash detection and another checking within the federated model, perfecting the final design and eliminating several flaws. Furthermore, 4D and 5D dimensions, representing time and cost management, are newly introduced in the project, characterizing a significant development in project management applications.[165] [166]

The United Kingdom, one of the leaders in the use of BIM, has determined since April 2016 that all government construction projects would, from then on, be mandatory use of BIM platforms according to the third level of BIM maturity (Level 2). Such action resulted in a tremendous turnaround in the field of construction in the country, which began to gradually migrate in the private sector to the broader use of BIM to execute new projects alongside the management of existent ones. Further on, a reflex was also

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[162] BibLus n.d.
[163] Borrmann et al. 2018.
[164] BibLus n.d.
[165] Borrmann et al. 2018.
[166] BibLus n.d.

noticed in other European countries like Germany, France, and Holland (one of the highest levels of adoption globally), where the BIM movement and new standards began to emerge and advance with its uses. Conclusively, within the past years, many governments are adopting new requirements introducing this level of BIM, especially concerning public works but also exposing substantial ambitions towards the transformation of the entire market.[167] [168]

The fourth and final stage for the construction sector is the BIM *Level 3*, representing *full integration of information within a cloud-based environment* whilst allowing interested parties to access the same constant information pertaining to a standard IFC format file. Also recalled as 'iBIM' (or integrated BIM), it promises to deliver better business outcomes, with fully integrated digital models used throughout the entire life cycle. In such a manner, a building's lifecycle can be managed from its earliest design conceptions, followed by its execution and maintenance.[169] [170]

Furthermore, at this stage, the project is based entirely on the implementation of BIG open BIM. Once already employing the 4D and 5D designs, the project lifecycle information (6D) is the latest add-on feature to the platform. At this sixth dimension, considerable improvements regarding sustainable construction deliveries may also be analysed, emphasising the necessity of the use of such a stage. BIM Level 3 is still in the future of the AEC industry, whilst the worldwide market is now driven by the utilization, implementation, and mainly the education of BIM maturity level 2 capacities and enhancements.[171]

Discussions on the evolution of BIM maturity levels have come a long way in the literature. A Level 4 maturity BIM, while still residing in its conceptual form, has already been widely mentioned around the subject, introducing concepts of better social results and well-being along with a 7D dimension targeted at facility management application[172]. Meanwhile, the future outcome for the evolution of maturity levels, their dimensions, and the amount of data generated within the platform continue to excite specialists and professionals in the field.

[167] Borrmann et al. 2018.
[168] Bimspot 2021.
[169] Borrmann et al. 2018.
[170] Bimspot 2021.
[171] Bimspot 2021.
[172] Designing Buildings Wiki 2021 (1).

5.3 Little BIM x Big BIM, Closed BIM vs Open BIM

BIM is a method, an ideology, not specifically software. Implementing methods and cooperation from all stakeholders drives the successful use of BIM software within an organization. Therefore, the introduction of BIM does not materialise instantly; it requires significant adjustments in internal and cross-company processes. Based on this fact, a gradual transition implementation is highly recommended, taking place through an optimized process to avoid unwanted changes in the basic functioning of the already established workflows. Accordingly, distinct technological levels and BIM implementation processes are categorized differently depending on intended software solutions and objectives.[173]

The most straightforward definitions come from the terms *'Little BIM'* and *'Big BIM'*. In the first, a single employee uses specific BIM software to perform a designated design task. Such a task can vary from design drawings to quantitative works, depending on the discipline and its intended objective. The solution is isolated within the corresponding field of action, not reaching the others involved in the project and being passed on only through drawings and documents. Consequently, despite the potential for considerable gains from the use of little BIM within the industry, it does not take advantage of all the potential present on the platform, and therefore it becomes limited within a unique solution for an individual discipline.[174]

On the other hand, Big BIM uses a collaborative variant involving consistent model-based communication among all stakeholders throughout the whole lifecycle of a building[175]. The model's data flow and coordination occur through digital technologies such as Internet platforms and central database solutions as a CDE.[176]

In parallel to this first discussion on BIM uses, a new categorization is added around which software will be employed during a project. When using software systems from the same supplier is required, the design carries a *'closed BIM'* setback. In contrast, when using other software is possible, and different vendors provide them, the process is called *'open BIM'*. While some companies on the market can provide a wide range of software geared to the same industry, specific tasks will always require specific

[173] Borrmann et al. 2018.
[174] Borrmann et al. 2018.
[175] Borrmann et al. 2018.
[176] Hengsberger 2019.

products that cannot always be found in the portfolio of the same vendor, which accounts for the various disciplines of a single project involves.[177]

Hence, it becomes clear that using an open BIM is commonly most used nowadays over a closed BIM solution. When so many disciplines are involved in the same final project, it turns out that different entities operating in different areas of knowledge require specific software for the development of their projects. In order to ease the exchange of information and allow access for different software and planners to the same format, an object-oriented data model denominated 'Industry Foundation Classes' (IFC) was created. Soon after its creation, it started to be used as the primary form of implantation of open BIM and therefore becoming acknowledged by several national standards and guidelines.[178]

Despite all the developments surrounding the use of BIM and a unique format standard for the collaboration of data, IFC still presents several information collection failures, resulting in data loss and poor communication. This pattern can and should be reversed with the expansion of the open BIM application, further developing the IFC format and reducing its current blockages. As any field under constant development, evolution occurs at a certain pace until perfectionist levels can be approached. However, when considering all the benefits of using open instead of closed BIM, information transition failures become insignificant compared to the whole sum of gains.[179]

5.4 BIM Software, Formats, and Interoperability

As already mentioned throughout this paper, BIM is not software but rather a platform compatible with a wide range of software and vendors. In this sense, the AEC industry counts with software for an abundant number of different tasks involving project development, ranging from initial planning to deep analyses and simulations and the final operational phase. The aspect is the most crucial differential when comparing the construction industry with all others, such as the automobile sector, which commonly stipulates the software their suppliers must use, reducing the number of formats among

[177] Borrmann et al. 2018.
[178] Borrmann et al. 2018.
[179] Borrmann et al. 2018.

files substantially. Positively, the dispute between vendors to supply the best product ends up stimulating the market, generating competition that evolves the branch.[180]

However, the problem remains the interoperability within this different software and the several formats native from each one of them. The term *'interoperability'* described in its essence means *"the loss-free exchange of data between software products by different vendors"*[181]*.* IFC has been the most common solution to address this problem, providing an international data exchange format. However, despite contributing enormously to the issue, it still features some operative flaws[182]. In the end, files develop into their native (e.g., Revit native format - RVT) and the collaborative (IFC, BCF, etc.) formats.[183]

At the same time, global software manufacturers such as Autodesk and Graphisoft, technology leaders in the segment ranking as the most popular BIM software companies with respectively 70% and 15% of market shares, provide products that span comprehensive parts of the design and engineering processes[184]. By doing so, they provide straightforward communication between different disciplines using their products for specific objectives, enhancing the interoperability between those files markedly while avoiding the precondition of going through standardization procedures.[185]

Along with the range of software vendors, the construction sector is still affected by some other frontiers that make loss-free data exchange more difficult. The preeminent ones can be said to be all the different disciplines and construction phases that constitute a single project that brings an uncountable number of different professionals oriented towards the project realization. Furthermore, as statistics present it, the construction industry is fragmented through several small to medium-sized companies, with 93% of European companies holding fewer than ten employees. The final resolution is the sector working with several companies collaborating for a specific project constituting a short-term working relationship and hardly the opposite.[186]

[180] Borrmann et al. 2018.
[181] Borrmann et al. 2018, p. 3.
[182] Borrmann et al. 2018.
[183] Baldwin 2018.
[184] NBS 2019.
[185] Borrmann et al. 2018.
[186] Borrmann et al. 2018.

5.5 BIM Collaboration Format - BCF

First and foremost, BIM Collaboration Format (BCF) is an open format tool that allows different disciplines within the AEC industry to communicate model-based issues, leveraging the developed federated model containing all the IFC designs shared among project teams.[187]

Its earliest development dated to 2009 and arose from the desire of implementing open communication technology for IFC-based workflows. Following similar origins as IFC, BCF was conceived by a partnership between Solibri and Tekla (both members of the buildingSMART International Implementation Support Group – ISG) and the Institute for Applied Building Informatics at the German Munich University of Applied Sciences[188]. In 2014 buildingSMART launched the second version of BCF, which has been undergoing updates and improvements over the past few years and is currently in use today.[189]

Following the success encountered by the development of IFC in the spectrum of open BIM, and the identification of clashes between different designs, BCF came to enhance the idea of how professionals channel the information related to constructive issues, providing an incredible spectrum of formatted data which includes: a detailed description of the issue, snapshots and pictures, responsible for the creation and solution of problems, creation and deadline dates, comments and much more – as briefly illustrated by figure 6.[190]

[187] buildingSmart n.d.
[188] buildingSmart n.d.
[189] BIM Track 2018.
[190] BIM Track 2018.

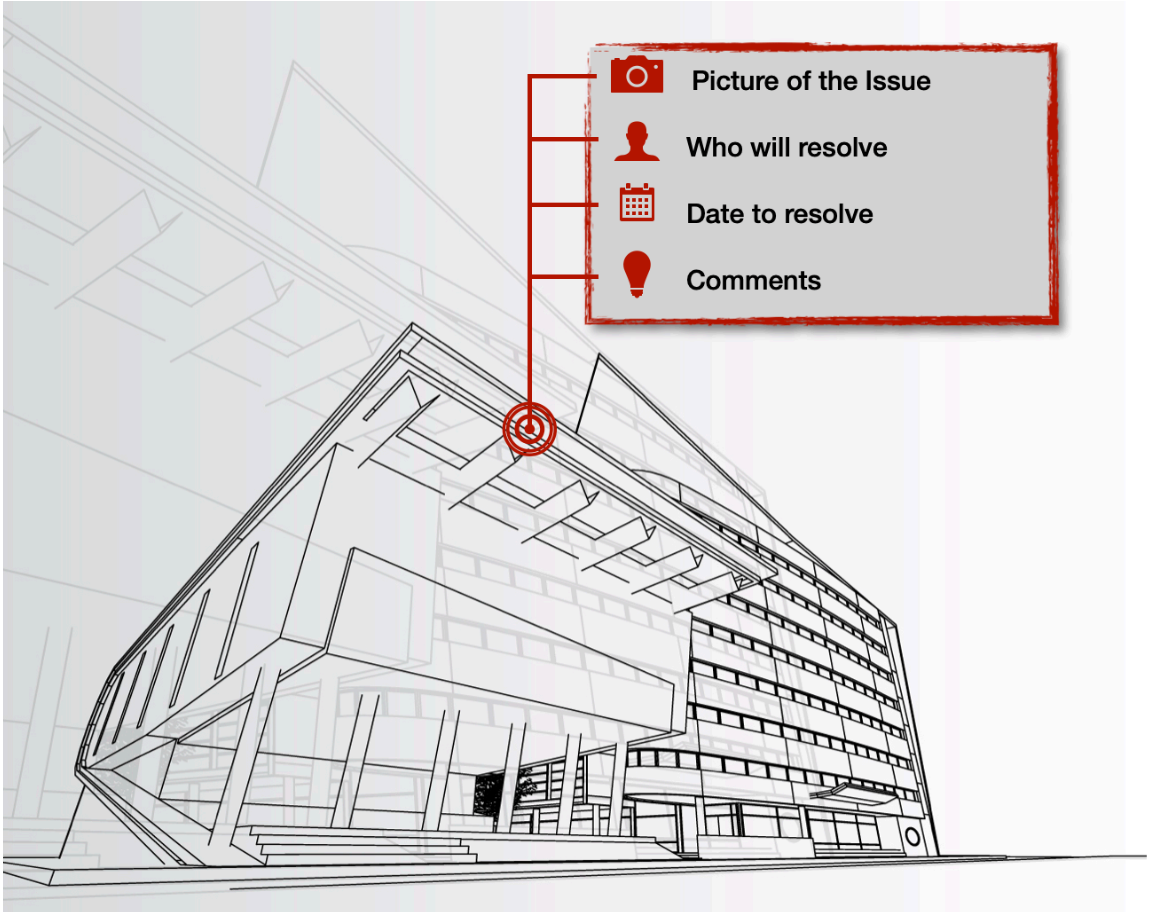

Figure 6: BCF Workability[191]

The communication between different BIM applications can be carried through a simple file exchange between different software platforms by using a service that connects software platforms directly - for instance, Solibri Office – or even utilizing a third-party BCF server connecting all information flowing between the stakeholders.[192]

The utilization of a BCF supportive software eases remarkably the issues communication, which before would necessarily run through a manual process of analysing, gathering, and reporting the issues before sharing them with the necessary professionals. Hence, it means a lot more work and time. The application now synthesises most of the process, significantly reducing the time and especially easing the understanding between the two communicating end-users. As industry professionals like to refer to BFC, it works like a BIM WhatsApp to report issues.[193] [194]

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[191] Adapted from Archjoe 2016.
[192] buildingSmart n.d.
[193] Baldwin 2018.
[194] BIM Track 2018.

Today BFC, like IFC, is a buildingSMART International openBIM standard and open to all who wish to benefit from it, either as a ‘file-based exchange’ or via a ‘web service’. The first is the most common and used by industry professionals transferring edited BCF files from user to user, which, unlike IFC, can be “roundtripped”. Alternatively, the latter option comes with the possibility of synchronising the information being created and edited within the file in real-time. It requires a web service to be based on, which means the precondition of having a BCF server where all the data is being stored, plus enabling free collaboration between project participants. As the intention of this research strongly embraces such collaboration, the latter holds a major focus throughout the development of this paper’s methodology.[195]

5.5.1 BCF Utilization

Following the BCF principle of facilitating and improving communication and IFC-based processes, it is of fundamental importance to note that throughout the different phases of construction of a project, the benefits arising from BCF use are also reflected differently related to each case. BuildingSMART (n.d.) subdivided to each phase of the project the following gains:[196]

- *Design phase:*
    - The assurance and checking qualities (QA/QC) of BIMs items are documented
    - The design coordination issues between different BIMs disciplines are analysed
    - Design selections, objects replacement, and material options classification
- *Procurement phase*
    - Coordination items and clarifications are bided
    - Generation of costs and information supply regarding objects and systems

[195] buildingSmart n.d.
[196] buildingSmart n.d.

- *Construction phase*
  - Assurance and checking qualities (QA/QC) of BIMs vs records of installations
  - Capturing of available items and materials plus coordinating substitutions
  - Preparation for handover to owner by collecting last-minute information
- *Operations phase*
  - Report of handover models and changes made to the building facilities and its components during occupation
  - Owner report concerning required upgrades[197]

Therefore, using BFC web-based communication is a tool that spread throughout the entire construction process. Moreover, with the increment of its use in the industry (as it has happened with the IFC format), the format will evolve considerably and benefit projects. The case study proposed by this paper will further depict the process of utilizing BFC, seeking to create a communication bridge between stakeholders aiming at developing this channel to manage knowledge within the organization.

5.6 BIM Standards and Protocols

Several national norms and guidelines have been produced to construct optimized cooperation and project delivery processes along with BIM implementation. The focus of BIM standards within AEC is always the same: managing information throughout the life cycle of building construction. Regardless of when BIM was implemented in countries, those that made it mandatory in advance are those where the platform better developed and created the first well-defined standards. Therefore, places like the Scandinavian countries and the United Kingdom today have better defined and concrete BIM guidelines than in countries where the platform has just been implemented or are still in the process of future implementation - not to mention the countries where dexterity with BIM use it is almost nil.[198]

Most of the BIM guidelines all around the world count with the same significant sections, containing a *Project Execution Plan* (PEP), a *Modelling Methodology* (MM),

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[197] buildingSmart n.d.
[198] Nicoleta 2019.

Levels of Details (LODs) and finally, a *BIM Protocol and Information Organization* (P&O)[199]. In order to reap all the benefits of implementing BIM, a common guideline for managing information is needed to avoid errors and allow communication between different facilities. As an initial step, BuildingSMART, as previously mentioned, developed Industry Foundation Classes (IFC), the leading software format for exchanging BIM data models[200]. In conjunction with this initiative, other globally known and used standards as PAS 1192-2, COBie and NBS (National BIM Object Standard) bornt as well.[201]

Simultaneously with the demand for common national standards and formats, a global standard has become necessary to keep pace with the platform's rapid evolution and globalization, affecting the construction industry and increased international projects and collaboration. The existence of only national standards inhibits agreements between countries based on national rules and regulations that make it impossible to benefit from using the BIM method entirely.[202]

Therefore, years after the formation of the first standards, the first global BIM standards, BS ISO 19650-1 and BS ISO 19650-2, were in December 2018 published as the first global BIM standards ever to exist, allowing communication and exchange of data to flow faster and more reliably between different countries/parties, rather than prioritizing national internal processes. The common international standard is based on the consistent English standard BS1192 and commits to bridge the gap left by creating so many industry BIM standards. Its effectiveness and scope concerning BIM implementation at a global level is still unknown and is being put to the test; however, the first step towards the complete standardization of information management within the platform has already been taken.[203]

While the ISO 19650 series describes the latest industry standards and how to succeed with information management within construction projects, BS EN ISO 19650-1 and BS EN ISO 19650-2 provide standardization throughout a project's life cycle.[204]

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[199] Designing Buildings Wiki 2020 (1).
[200] Poljanšek 2017.
[201] Nicoleta 2019.
[202] Nicoleta 2019.
[203] Nicoleta 2019.
[204] Çekin & Seyis 2020.

5.7 Knowledge Management and BIM

The introduction of one of the first and most efficient IT techniques in the AEC industry – the object-oriented CAD – in the early 1990s by companies such as AutoDesk, GraphiSoft and Bentley Systems revolutionized the field and its use for knowledge management within it. Initially, 'data objects' containing high levels of information, whether graphical or not, could be real for the first time, greatly expanding storage and retrieval of projects information whilst logically linking them to its design. Later, alongside the development of network computing and the internet, companies were able to work collaboratively by sharing information about buildings with each other, serving as an introductive sample to what we know today as one of the main features of BIM, the interoperability among projects.[205]

Building Information Modelling, as already described in chapter 3, came to revolutionize the field. The application of knowledge management using BIM as its primary tool has also been evolving continuously and boosting companies' performance. Its proposals add tremendous value to managing relationships between building components over CAD solutions, going far beyond the use of object-level information whilst representing all the intended relationships within the same.[206]

The tools and, above all, the collaboration and communication with which the platform allows individuals and teams to benefit from, supply knowledge management with a great new engine for its development in the digital evolution of construction. Furthermore, by employing a CDE to store and manage building information, the company automatically creates an enormous information retrieval source, aiming at knowledge creation. Nevertheless, all modifications being made during design and execution are already updated directly, thus providing an up-to-date project from the beginning to its end.[207]

[205] Cerovsek and Katranuschkov 2006.
[206] Boddy et al. 2007.
[207] Howard & Björk 2008.

5.8 Data- to knowledge-centric vision transition

Because the AEC sector is fragmented and communication between teams is often lacking, information inconsistencies and regulatory compliance issues have become commonplace[208]. In this sense, IT has been addressing most of those challenges counting with the great support offered by the information systems, which play a significant role in the daily AEC operations. Information systems, which have already been previously mentioned in early chapters, must fulfil specific criteria so that they can be genuinely beneficial to the construction industry knowledge management:[209] [210]

- Appropriate data acquisition methods development and proposal
- Delimitation and use of suitable models to depict information
- Integrated repositories easing data storage and retrieval
- Appropriate data analysis approaches supporting decision-makings[211]

The amount of data produced is vast, and its management presents many evident challenges throughout the building lifecycle. Moreover, several authors have been referring to the term "information overload" as a form of attributing the increasing generation of information that has accelerated its pace since the 21st has begun[212]. From the transition from CAD documents to BIM methodology and the several other software supporting it, the number of heterogeneous construction archives has been multiplied manifold along with the demand to manage them.[213]

In order to avoid information overload, or better saying, to make information management possible, its classification is indispensable. Targeting specific data to the right end-user essentially eliminates the generation of data overload driven to irrelevant masses. Herein lies the importance of information management and IT systems' ability to integrate and manipulate a myriad extent of different data formats. However, according to Shen et al. (2010), there are still many obstacles to integrating different information systems, primarily due to the lack of general common standards.[214]

[208] Rezgui et al. 2010.
[209] Martínez-Rojas et al. 2015.
[210] Kuo 2019
[211] Kuo 2019
[212] Hicks et al. 2008.
[213] Demian & Balatsoukas 2012.
[214] Cho et al. 2013.

Hopefully, with the appliance of common international standards, as highlighted in chapter 3, the interoperability between IS may enhance apace with the quality of information flows. Meanwhile, the existence of detailed classifications and their correct use by the generating user, who in turn directs the information to its direct receiver, still seems to be a very plausibly accepted solution.

5.8.1 AEC common knowledge sharing practices

The AEC industry is famous for maintaining the same practices for a long time without evolving in them. The exchange of knowledge is one of the most notable. Engineers and builders' social and human-oriented nature lies in sharing knowledge and solving problems through oral communication, whether in physical presence or through mobile devices. They use their knowledge to provide solutions that are hardly reported and stored for future developments. The time, cost, and cognitive effort of storing information related to decisions serve as the reasons for the justification for not complying with the process, disregarding the enormous loss of tacit knowledge, which since the beginning of this research has proven to be the leading cause of inefficiency in retaining knowledge.[215]

Encouraging the organizational process that foster the redemption of tacit knowledge must be understood as essential for the field and entities. Following the principle of knowledge creation (SECI model), externalization is associated with the acquisition of information plus the "understanding" underpinned by internalization carried out by AEC practitioners rather than adding time and cost in a short-term perspective will decrease both in the long run. However, such a process can only be achieved through a deep understanding of the importance of the concept.[216] Kuo (2019) reaffirms this by saying that the "'*real knowledge creation process is dynamic, inconsistent, multidimensional, and only possible when there is a transformation between the tacit and explicit dimensions of knowledge".*[217]

Besides, whenever IT systems failures occurred, several arguments would arise as to whether the failures were induced by technical vs human factors, calling into question the efficiency of the joint work between both and demanding a culprit. The

[215] Hertzum & Pejtersen 2000.
[216] Demian & Fruchter 2006.
[217] Kuo 2019, p. 34.

misunderstanding of the matter lies in its comparison, which is targeted to place both extremes against one another alternatively of using them jointly. The choice of social ‘and’ technical placed together with better reflects current situations within the AEC industry. Consequently, their failures too. Both the human being and the information system carry their limitations and must be understood as such, avoiding unnecessary judgments. Thus, when both are understood as a single entity, the KM domain can reap the maximum benefits for knowledge creation.[218]

The stance within this research is that IT tools in AEC perform supporting individuals in their development, involving both social and behavioural aspects inherently. Therefore, IT efforts are directed towards perfecting the tasks produced by humans, heightening them to a level unreachable by the individual. This methodology will show how their mutual work application producing real-time collaboration across disciplines leverages the evolution of knowledge within all parties involved, helping to close the gaps between KM failures.

[218] Kuo 2019.

6. Research Methodology

The methodology presented by this paper embraces mainly the subjects of Knowledge Management (KM) and Building Information Modelling, proposing the latter as a platform for the development of knowledge management and, therefore, a tool for the achievement of the first. Throughout the literature review, we came across a matter already well known in several fields of science and knowledge – KM – and a second that is also profoundly established within the AEC industry - BIM.

Aiming to achieve the aforementioned objective by proposing new methodologies available in the market, BIM was linked to utilising BCF format in a real-time cloud-based platform. Despite its recent development, the technology has been gaining strength and respect within the scope of the digitalization movement in the civil construction field due to the significant enhancement it offers for the flow of communication and information between disciplines and stakeholders.

BIM, as its name already indicates, is thitherto the best information management methodology within the AEC field and with a range of software commonly categorized within the standards of a TPS (Transaction Processing System), indicating systems operating and processing all the transactions subsequently stored in an entity's database using computerized systems[219]. However, BIM can effectively act in all the pyramidal areas of Information Management, being yet essential as Decision Support System, Management Information System and Executive Support System, given its power of information. As we will see below, it works extensively, producing dashboards containing unique project's data.

Therefrom it materializes the need to use such an enormous range of information in the generation of knowledge, thus proposing the utilization of IMS to create a KM spectrum. Despite the innumerable ways of reaching this objective, this research has decided to seek it using BCF and one of its real-time cloud-based applications. The reason lies in the idea of being a technology in its onset with enormous potential to reach over the subject. When activated, the combination represented research divided between qualitative and quantitative methods so that together they could answer the following questions intended by this research:

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[219] Azimuth Interactive Inc. 2006.

- Can BIM be considered a Knowledge Management System? If so, how?
- How can BCF be used as a real-time tool enhancing experienced-based knowledge during design and execution phases?
- What practices and methods would make such a union effective and widely used within the branches of Architecture/Engineering/Construction projects?

In addition to answering in-depth the first two of the five questions introduced at the beginning of this research paper, the literature review also provided a substantial introductory basis to resolving the remaining three described above. The preceding three chapters offered valuable insights that lead to a higher understanding of the development now presented. Hereby, the methodology heads to a more concrete answer for the addressed questions through an in-depth analysis of the proposed case study.

The combined qualitative/quantitative technique was thus chosen to provide a richer and more comprehensive understanding of the research area[220]. Quantitatively approach, for instance, was decisive to identify the number of clashes or construction flaws (which is a process intrinsically linked to the use of BCF real-time tool) that might be committed throughout the execution of a given construction project. Therefore it provided, based on numbers, the essential information leading to the qualitative approach, where data would thus become reported documents aimed at knowledge retrieval and sharing.

The main application used for this analysis was the Solibri Office, a well-known and core product for model checking and collaboration. Solibri is founded on the concept of an Open, BIG BIM supporting building models from all major BIM software products. Through its brand-new feature, the Solibri BCF Live Connector, the communication between the stakeholders became magnificently more straightforward and hence the flow and storage of information. Furthermore, the information now can be exchanged in real-time, thus providing instant communication between stakeholders.[221] [222]

Solibri BCF Live Connector platform was therefore used in two ways: providing real-time investigation of design flaws and pointing out conflicts directly to those responsible alongside with comments, proposed solutions, and the setting up of deadlines for their resolution; and promoting a bridge between the builder, BIM coordinator, and the

[220] BetterThesis n.d.
[221] Solibri Inc 2019.
[222] Solibri Inc 2021 (2).

designers, indicating the differences between the executive process and the design requirements, which cannot consistently be replicated perfectly during execution on-site of the same.

Nevertheless, in both cases, what information should be pulled from the model and which approaches should be taken to perform each of these coordination tasks still predominantly relied on the expertise of either the BIM Manager or the constructor. Consequently, the incentive of both to contribute with valuable comments and personal assessments about the project's development during its execution is fundamental, feeding it with their knowledge and experience.

Such misalignment in the acceptance of digital communication between designers, BIM managers and builders is still profound. It must undoubtedly be a pivotal contributor to enhance the project's performance while generating knowledge that avoids the same inconsistency to be repeatedly happening by new or future stakeholders. Although collaboration amid the design phase plays a crucial role, the critical stage of information exchange during the construction phase carries tremendous importance. Most design decisions have already been made, and digital communication's misalignment is even higher, as shown in Figure 7 below.[223]

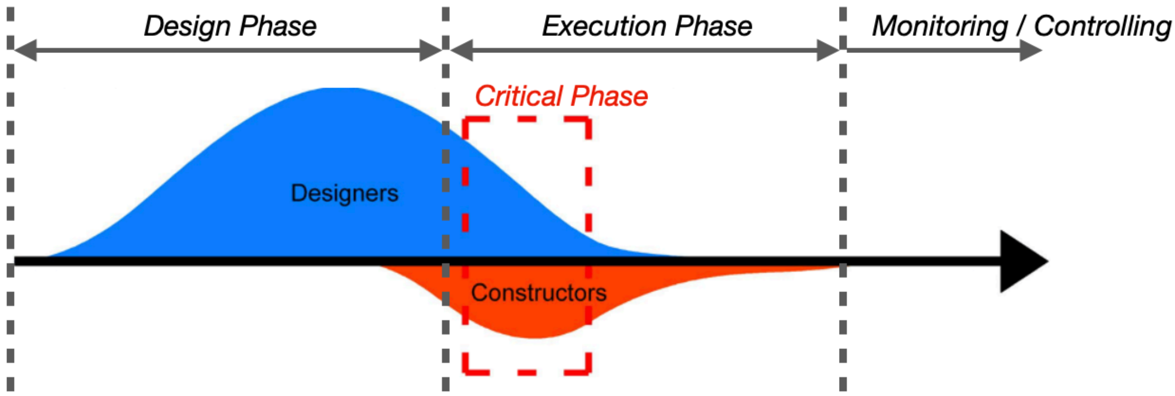

Figure 7: Typical BIM Project Resolution During Design and Execution Phases[224]

BIM and, recently, BCF real-time tools have been encouraging stakeholders to produce far greater levels of information. This process promotes the common generation of knowledge exchange amid them, mainly through externalising tacit experimental

[223] Godden & Mansel-Thomas 2016.
[224] Adapted from Godden & Mansel-Thomas 2016.

knowledge into readable explicit knowledge, with professionals using their expertise and understanding of the discipline to provide optimal insights and solutions.

In this sense, both the BIM coordinator and the constructor can be activated as a source of tacit knowledge and a genuine contributor to the design evolution of the current project and the successive ones, feeding in solutions, enhancement comments based on their own experience and emerging from practical intolerances and as-built conditions throughout the construction process[225]. This would significantly avoid the loss of knowledge within organizations, the central aspect coined of their slower pace of evolution and one of the biggest problems faced concerning the flow of employees.

When stored correctly in a CDE in the form of, for example, specific documents or reports, this practice would allow knowledge to be accessible to all intended organizational collaborators and retrieved at any time. Using databases, more people and sources of documentation would serve as further information to the individual knowledge generation.

Thereby knowledge flowed through this experimental study between individuals to organizational prospects and vice versa, mainly from the individual experiences or from the set of groups of knowledge combined and coming from several bodies to form one within an entity. The organizational memory was thus followed according to its main structural line, commencing in the decision's environment to the individual/group, who suffering internal and external influences, was able to create further knowledge promptly to be communicated, shared, and retrieved. Most knowledge was built on top of information that software analyses and models were providing.

Therefore, the Solibri Office software, together with the CDE, also acted as an Organizational Memory System built mainly on data, communication, and document management, enhancing human capabilities such as memory and information processing. In line with the constructed structure proposed by Stein and Zwass (1995) in section 3.3.2, it is possible to mark it as an Integrative Subsystem or an Adaptive Subsystem, evolving along with the construction environment. The process superbly facilitated the dissemination of project results among the organisation members, being accessible at any time by anyone with permission to do so.

[225] Godden & Mansel-Thomas 2016.

The only possible way to reach such interests was through a BIM Maturation Level 3, which proposes the total integration of information in a cloud-based environment. Without it, BCF real-time applications have no operability whatsoever. For this reason, this research presents a complete implementation of a BIG Open BIM approach, enjoying most of the benefits that the method can offer its user and organization.

The following chapters 7 and 8 present a methodology for data collection routing into information management and, finally, knowledge creation. They are justifying which and how the methods of knowledge exchange (highlighted by the SECI model in section 3.3.3) were made effective using the BIM collaboration format through a real-time cloud-based platform, optimizing projects, supporting organization’s decision-making, and especially retaining knowledge during the flow of employees leaving the company.

Furthermore, it is essential to highlight that the developed model only captures knowledge converted into an explicit form. It is of the author's acknowledgement that any sort of tacit knowledge that cannot be made explicit, despite being very important, does not fit with the intentions of this research.

Thereby, a case study was created to validate the model and achieve the research objectives. Within it, the would-be BIM manager played a key role, presenting his knowledge to correct early design flaws in collaboration with the project designers, brokering and channelling the knowledge arising out of the builder, and finally analysing and reporting the findings throughout the project in a way that would provide easy access to company members. Knowledge within this proposed case study emerged from the project's conception aiming to be provided to the right people at the right time as it could happen in a real case project, thus supporting the decision-making and execution of the project at all stages.

6.1 Case Study Data

A Brazilian construction company provided secondary data for the construction of the case study. The organization had never worked on a BIM collaborative environment before, and then most of the initial works had to be carried out before further analyses. Their models - architectural, structural, and hydraulic - have been put together, forming thus the federated model, from which all the primary data was thus originated.

Thereafter the methodology was sub-divided within two different data analyses embracing both the interconnection between the designers and the BIM manager, occurring in the earlier phases of the project, and the correlation between design and execution, represented by the relation between the designers, BIM manager and the builder, carried out through the intermediate project phase.

6.1.1 Secondary Data – 'Residencial Âmbar'

The designs making up the federated model were conceived by the Brazilian construction company *Engeter Engenharia.* One of its socio-owners, Mr Rodrigo Roehrs, agreed with the availability of its plants so that the development of this study could be carried out. The development is called *Residencial Âmbar* and is located in the city of Ijuí, Rio Grande do Sul/Brazil, on the street *Rua Goias* number 105.

The project is in its execution phase, where, according to its developers, 16% of the building execution has already been completed. Hence, the secondary data is limited to the current implementation phase, given the impossibility of generating future data where the project has not yet been reached. From that point on, real-life assumptions were created to produce necessary data to continue with the final analysis. The table below accurately depicts the main steps being so far undergone, covering the executive phase of the building's construction at all its levels. Mr Roehrs provided all data.[226]

[226] Roehrs 2021.

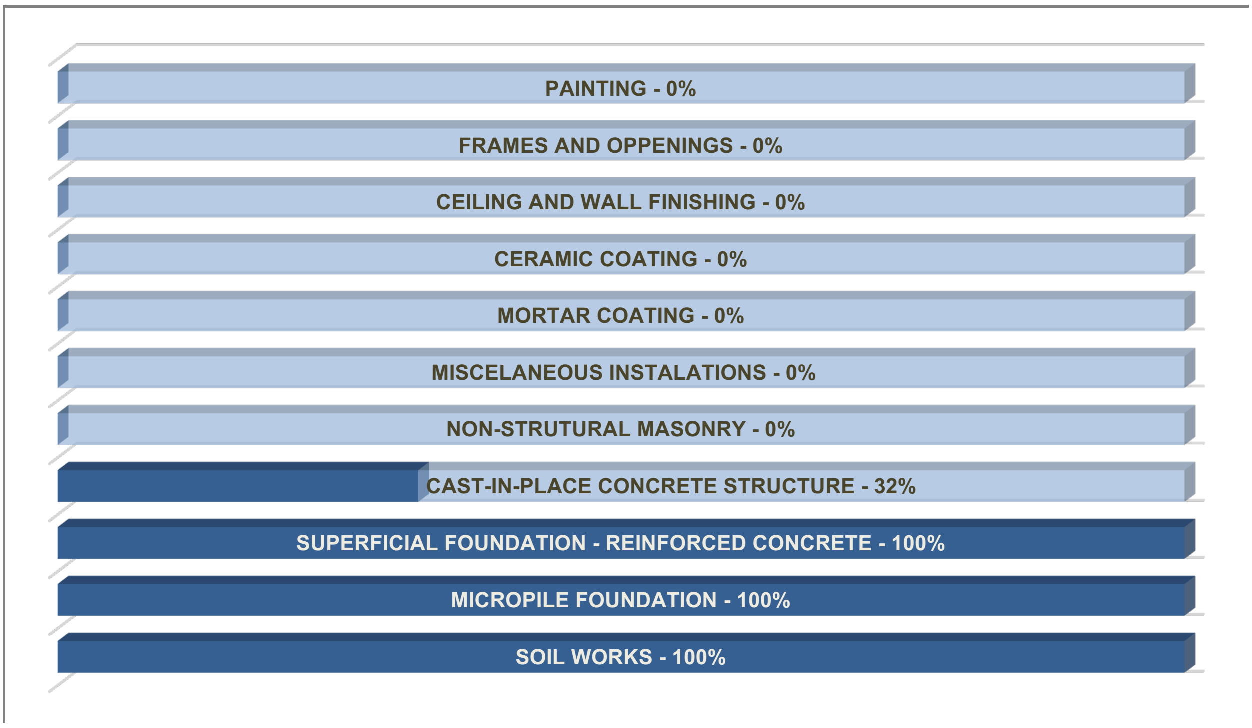

Figure 8: Current Project Stage – Residencial Ambar[227]

Hence, the structure is in its essence based on cast-in-place concrete, which is commonly used in this region of southern Brazil. The slabs were all post-tensioned, thus providing a wider use of the free area within floors resulting from the considerable reduction of columns and beams. Furthermore, the finishes follow a high level of quality due to excellent materials and outstanding workmanship.[228]

The building counts with 16 floors, two of which are garages and located in the underground, a ground and a second floor embracing recreational facilities for its inhabitants, and a further 12 storeys aimed to residential purposes - no commercial facilities are integrated. The entire building corresponds to an area of 12,436 m^2. The illustration below was produced to promote the establishment, faithfully representing what the building will look like when completed. Nowadays it is considered one of the main developments of the city.[229]

[227] Own source, based on information provided by Roehrs 2021.
[228] Roehrs 2021.
[229] Roehrs 2021.

Figure 9: Publicity Render of the Building[230]

The models were all made by outsourced designers, with no direct employment relationship with the construction company. Engeter Engenharia works under the label of being a development and construction company hiring designers for the models' productions and diverse smaller contractors to fulfil the on-site job site. In this sense, an architect and two engineers were responsible for architectural, structural, and plumbing projects[231].

The following chapter will oversee the details of the models while depicting the process of assembling them to form the meaningful federated model of this case study. Furthermore, it proposes an introduction of the further analyses that underwent creating the main primary data.

[230] Roehrs 2021.
[231] Roehrs 2021.

6.1.2 Federated Model and CDE

As already mentioned in this paper, the federated model comprises three main designs: architectonic, structural, and plumbing. These three categories are mandatory for any project approval in Brazil and therefore are utilized to assemble the final model. HVAC projects, constituted of the installation of private air conditioners, are not always necessary for this type of construction due to the climatic conditions proposed by the region, being up to the owner to decide whether they should be a requirement for the execution of the building or only implemented by future buyers. In this sense, it was not part of the final federated model.

After receiving such projects, the first visual analysis was carried out identifying their origin, the BIM software in use and their native formats. Given the pre-condition of having all files saved in the IFC format before combining them in Solibri, some processes and, therefore, the help of the designers were necessary. The table below provides a summary of the information.

	Architectural	Structural	Plumbing
Software	Revit	Eberick	QiBuilder
Format	.RVT	.PRJ-CAD	.PRH-CAD
IFC Conversion Process	Requested to the designer	Requested to the designer	Requested to the designer

Table 2: Designs Conversion Process Information[232]

All conversions were made by their responsible designers, leaving me the sole responsibility of putting them together. During the transfer of the architectural model, I was communicated by its architect that the structural model was extracted during its conversion to IFC to ease the federated model assembling. He furthermore claimed that through previous communication between both parties (architect and structural engineer), he had modified the first architectural design to the requirements of the structure, remodelling it accordingly. Such absence can be seen in Appendix A. The succeeding Appendix B and C conclude the visualisation of the projects, respectively portraying the structural and MEP models.

[232] Own source.

In possession of all projects in IFC’s formats, the further step was to upload all models within the Solibri Office models tree and set the correct spatial positions for each. The only model not sharing the exact locations was the structural one, promptly placed at the precise coordinates as the others. For the first time, the result was the federated model of this case study, as illustrated by the figures below, representing the entire development and, secondly, a reference floor plan.

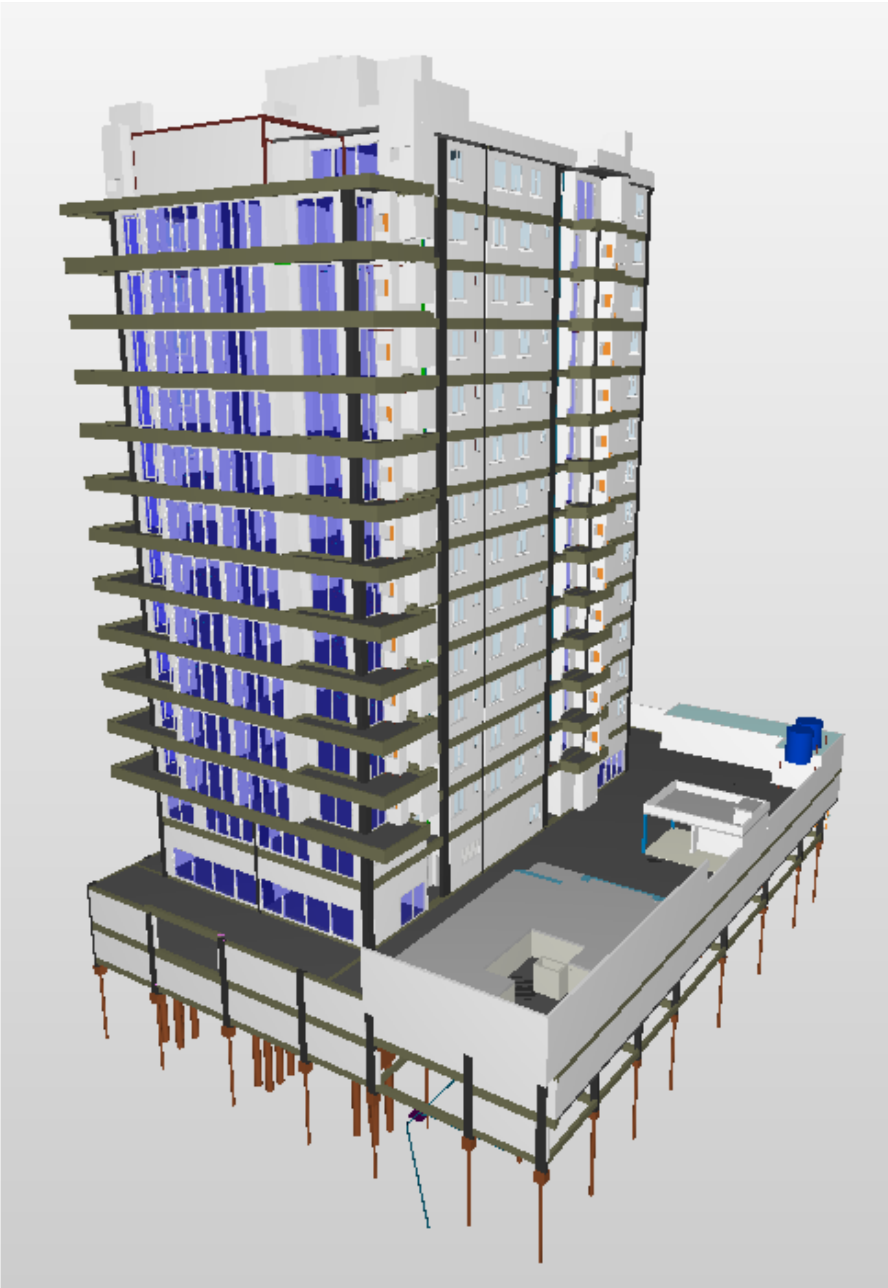

Figure 10: Federated Model[233]

[233] Own source, extracted from Solibri Office Software.

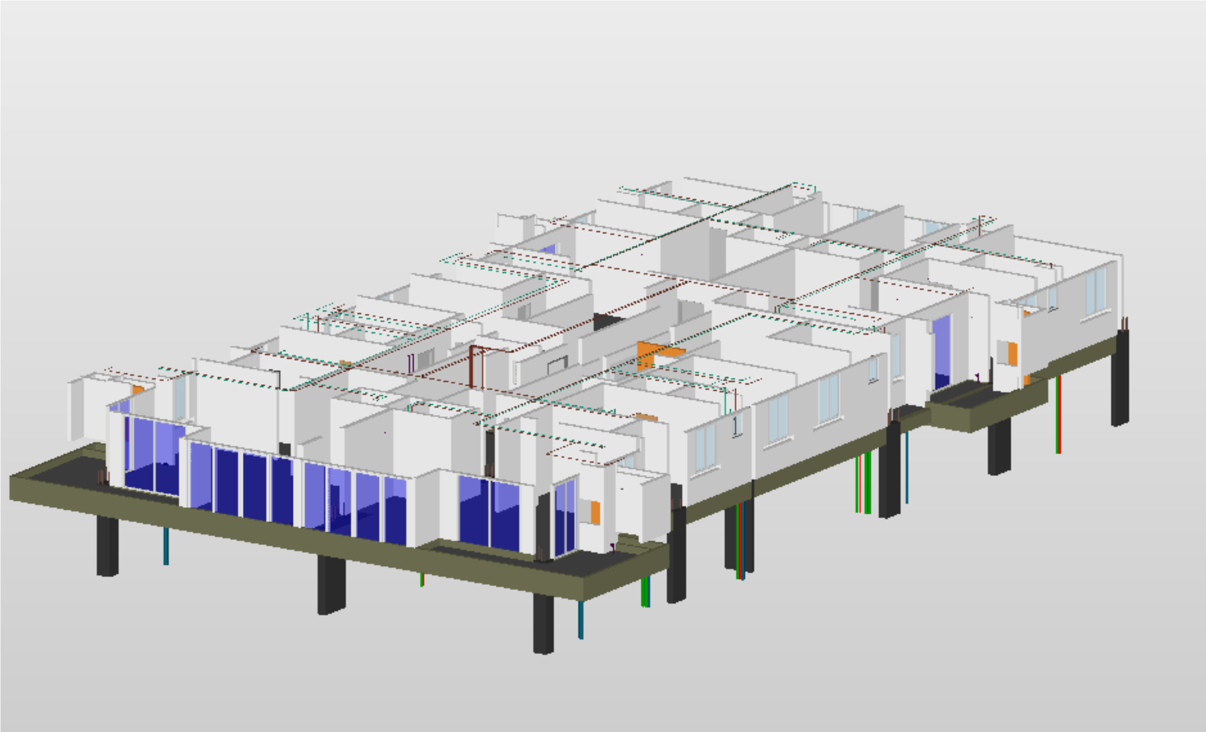

Figure 11: Federated Model – Reference Floor Plan[234]

Based on this federated model, most of the following analyses took part using the software Solibri Software and BIM Track platform. As already mentioned over Section 5.5, Solibri BCF Live Connector provides a channel between Solibri Software and a cloud-based BCF server, supporting two types of connection technologies: first, a direct connection linked exclusively to BIMCollab (CDE developed by KUBUS); and second, a standardized connection offering a range of other common data environments supporting the means of BCF API. The latter is a supportive mechanism of exchange of BCF issues between software applications, where data is exchanged via a web interface using URL-encoded query parameters and Json bodies.[235]

The second common data environment option was chosen for this research analysis, utilizing thus BIM Track as the leading communication platform between all stakeholders via a BCF API port. BIM Track is a live cloud-based web platform that offers direct support and connection within the Solibri BCF Live Connector tool. It is built to OpenBIM standards and developed by Building SMART, providing excellent and

[234] Own source, extracted from Solibri Office Software.
[235] Sollien 2020.

secure collaboration and communication between different project stakeholders while offering an accurate and user-friendly interface.[236]

BIM Track held primary relevance for this case study (reaffirming the importance of CDE's in today's projects and organizations). Therein is where all presumed experiential knowledge was converted, stored, and analysed, whether from the designers, BIM managers or builders. Its database would have opened for information to be retrieved by any collaborators, enabling instant investigation. By using it, more stakeholders and their contributions served as a source of information to individual's knowledge retrieval/creation within the company at any time.

Alongside being a database, BIM Track still provided numerous charts and dashboards where one could immediately overview the project's performance and information concerning its members and their activities within it. Thus, in association with Solibri BCF Live Connector, BIM Track web-based platform supplied the BIM manager with most of the necessary information to build up the final reports and findings of this research, magnificently improving the company's knowledge reach.

[236] BIM Track 2020.

7. Case Study Data Analysis

Throughout this chapter, the case study primary data is created and analysed built upon the federated model. Data is structured among two main sections: the design phase data analysis and execution phase data analysis. According to their coined terms, they expose how data were generated and collected between the design and execution of the proposed case study. Despite using the same tool for communication (Solibri), the origin of the information and the stakeholders diverged slightly, with a meaningful addition of the builder and his knowledge in the latter. Nevertheless, the processes are well portrayed as follows.

7.1 Design Phase Data Analysis

Performing coordination tasks, especially during the design phase of a construction project, commonly involves using, transferring, and applying individuals' knowledge and experience to models. Going back to how old practices took place (and still take) within the AEC field, the project coordinator, comparable in some instances to today's BIM manager, would generally be a very experienced architect/engineer with adequate knowledge to identify critical clashes. The process would undergo analysing the clashes, classifying by their degrees of importance, and providing designers with suggestions to solve issues or make decisions themself based on their knowledge and expertise. [237]

Hence, following the natural conception of a construction project, the first analysis on this case study embraced the relationship between the BIM coordinator and the designers, identifying and communicating clashes among the parties, emphasizing the knowledge conversion throughout the process.

The BIM coordinator, in this case, was defined by an internal user who represented the construction company, while designers were defined as an external, single, and central recipient within the BIM Track. Centralizing all designers into one aims to ease the communication of issues during analyses and the development of the paper. Further specific explanation on how the process took part is given throughout the following sections.

[237] Li & Leite 2014.

The tools and platforms used by the BIM coordinator were the web browser google chrome, enabling access to the BIM Track website to handle all necessary activities within it, and Solibri Office for the other coordinative actions. Likewise, in addition to the previous nominated applications, the designers were linked to their software of choice to develop each discipline's models - Revit, Eberick and QiBuilder. The figure below depicts interactivity between parties while illustrating their utilization of IFC and BCF formats and a cloud-based environment for sharing and receiving information/knowledge under a BIM methodology.

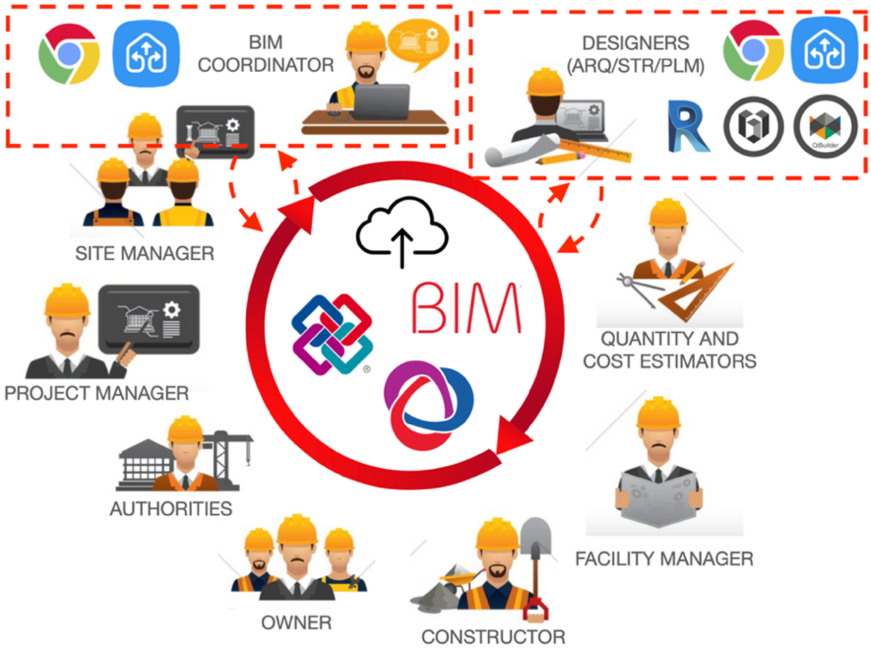

Figure 12: Clashes Analysis Stakeholders[238]

Following the explanation given and to provide a more detailed representation of the entire evolutionary process of an analysis given in the design phase of a project, the following art subdivided the eight main steps from the design concept to its final revision. In ongoing projects, when the 8th stage is reached, it is common to shift back to the 'Visual Analyses' and restart the process all over again till all the designs are perfectly synchronized before the execution starts. In addition, the illustration also informs all the applications utilized during each of the design phases.

[238] Own source.

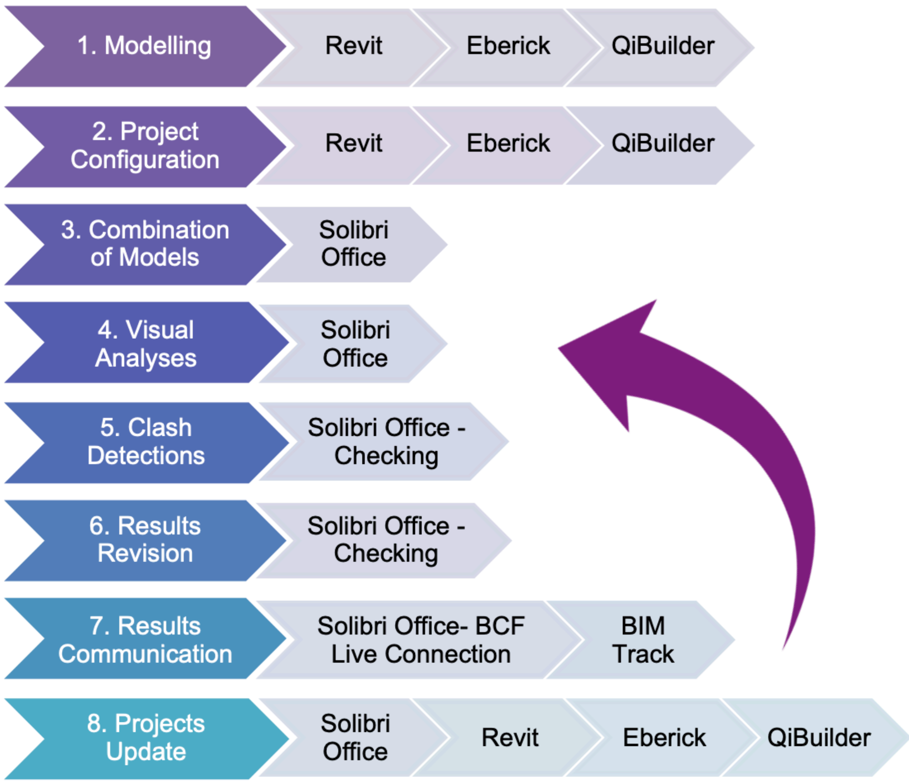

Figure 13: Design Phases Structure[239]

Knowledge can be seen in a comprehensive form already within the first phase, where designers use all their experience to create the best and most innovative design possible. From the third stage onwards, the knowledge capture shifts to the BIM manager, who makes use of all his/her experiential knowledge to combine and analyse the project, fulfilling all the following phases until everything is communicated to the designers, giving start to the cycle of externalization, retrieval, and internalization of knowledge through the design phase.

About this case study, the analysis took place directly from the 3rd to the 7th design phase. From the combination of models – explained in-depth in the previous chapter – and the visual studies of models position and condition within the federated model, the clash detections took part, initiating thus the verification of design flaws and incompatibility between different disciplines designs. The projects updates (phase 8) were not executed, and therefore only a singular cycle of design evaluation was made within this research.

[239] Own source.

7.1.1 Clash Detections

For the clash's detections, the predefined role for 'BIM Coordination' residing in Solibri model checking was picked out, and within it, six rulesets to proceed with the verification of models. They are further described as follows.

1. *BIM Validation Architectural:* It includes rules that validated the Architectural model and its components individually, not overly verifying intersections with other model disciplines
2. *BIM Validation Structural:* It includes rules that validated the Structural model and its components individually, not overly verifying intersections with other model disciplines
3. *Intersection Between Structural Components:* It checked all the hubs within the structural model, pointing out the anchorage failures between structural elements and their overlapping
4. *MEP models and Architectural model:* It verified the characteristics of the MEP model within the architectural model, mainly indicating the intercepts and regulating distances between them
5. *MEP models and Architectural model:* It verified the characteristics of the MEP model within the structural model, mainly indicating the intercepts and regulating distances between them
6. *Structural versus Architectural models:* It verified all the intersections between the structural and architectural elements, highlighting mainly the architectural components superimposed on the structural ones. Typically, when the architectural model itself contains structural components (which is commonly the case), it provides the identification of the incorrect positioning and dimensioning of structural elements within the architectural model, pointing out when the structural elements present in the structural model do not correspond to those used in the architectural project, leading to the alteration of such features in the latter. Due to reasons already described in the previous section, such checking did not occur during this research[240]

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[240] Solibri Inc. 2021 (1).

Before carrying out the verification of the projects, the BIM manager's knowledge was for the first time activated for the adjustment of rulesets parameters, minimizing unnecessary issues regarding this specific project. Adjustments were made considering his/her knowledge of this project characteristic, location, and company environment. Such parameters can always be accessed and studied by future professionals who would replace or even assist the BIM manager. Each project carries its parameters and serves as an aid to the delimitation of future developments and represents how an organization considers the analysis of design flaws.

In this specific federated model, during the models and visual analysis assembly, it was noticed that there was a difference in heights between the floors in the mechanical project concerning the other architectural and structural ones (which had the exact measurements). This contrast meant several clashes identification by the software and, on many occasions, their duplication as well. In this sense, the 'Distance between components' rule was cut out from both the 'MEP model and architectural model' and 'MEP model and structural model' rulesets to avoid so many clashes concerning the same components. In addition, some other parameters underwent minor modifications to fit the actual project specifications better. Thereby, the federated model was evaluated by the Solibri Model Checker, framing the project's confrontations in a range of problems from low to critical severity, as informed in the table below.

Rulesets	Δ	Δ	Δ
MEP models and Architectural model	1240	5536	4251
MEP models and Structural model	550	4912	0
Structural versus Architectural Models	310	2469	39
BIM Validation - Architectural	621	1238	66
BIM Validation - Structural	369	453	26
Intersections Between Structural Components	2204	952	0

Where:

Δ Issues with Critical Severity

Δ Issues with Moderate Severity

Δ Issues with Low Severity

Table 3: Solibri Clashes' Checker Results[241]

[241] Own source.

Therefore, the checking resulted in 3,702 Critical Severity Issues, 15,628 Moderate Severity Issues, and 4,437 Low Severity Issues. Before carrying out any analysis of achieved results, the corresponding percentages of clashes ordinated by degrees of severity and discipline were as follows:

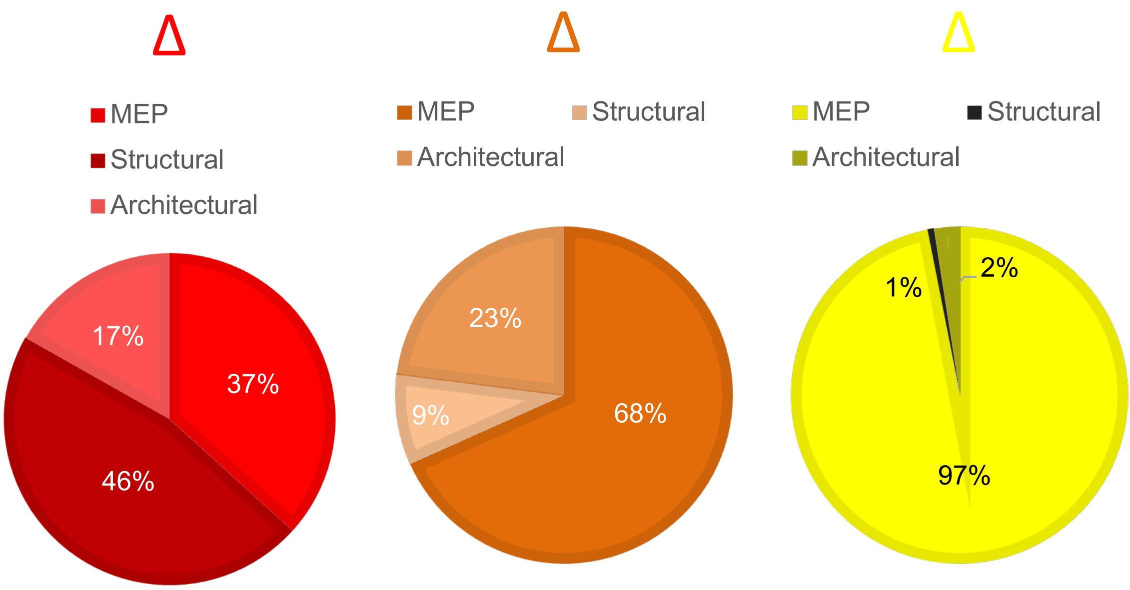

Figure 14: Clashes Detections Percentages by Disciplines[242]

It is noticed that the plumbing project is the one that collects the most clashes in an overview, holding 67% of the total count against 18% for architectural and 15% for structural. Moreover, apart from critical severity problems in which the structural one is the highest percentage, the plumbing model has the most significant participation in the other two levels. These percentages, however, will soon undergo considerable changes in the following subchapter, where the selection of all accepted and rejected items will result from the sifting of the current outcomes.

7.1.2 Results Revision

The automated clash detection, as already stated, often yields numerous false positive issues irrelevant for the project and requires no need for changes in design or construction. In this phase, the knowledge of a BIM manager is concentrated on identifying them, eliminating the false positives and proposing solutions to the real issues. The

[242] Own source.

results revision and the clashes detection are necessary to generate data for further analyses regarding knowledge retrieved upon designs performance.

Therefore, the results obtained with the verification of the clashes underwent an in-depth review to qualify them as either rejected – actual issues – or accepted – non-issues to be disregarded. The revision went through each ruleset, achieving the following results:

Rulesets	Δ	Δ	Δ	X	✓
MEP models and Architectural model	1240	5536	4251	10252	775
MEP models and Structural model	550	4912	0	5462	0
Structural versus Architectural Models	310	2469	39	860	1944
BIM Validation - Architectural	621	1238	66	355	1570
BIM Validation - Structural	369	453	26	20	826
Intersections Between Structural Components	2204	952	0	2	3154

Where:

Δ	Issues with Critical Severity
Δ	Issues with Moderate Severity
Δ	Issues with Low Severity
X	Rejected Issues
✓	Accepted Issues

Table 4: Solibri Clashes' Checker Revised Results[243]

As one can notice through this new evaluation, most of the results related to MEP projects were rejected - represented by the first two sets of rules on the list - while a significant part of the architectural and mainly the structural clashes was accepted. If a BIM manager had to report the findings, they would be closely related to the explanation given in the following paragraphs.

7.1.3 Results Revision Report

The hydraulic project had so many clashes, and essentially most of it was rejected due to the same principle explained in the previous subchapter, which is the difference in height between the floors. Furthermore, the second major flaw of the designer

[243] Own source.

mistakenly analysed the structural design of the building. When considering the structure of the construction as consisting of post-tensioned slabs and resulting from the almost absence of internal beams, the hydraulic designer followed the same height level throughout practically the entire floor area, disregarding the existence of the fundamental external beams that provide all the anchoring and prestressing of the slab to themselves and the few internal beams of the engine room/staircases. The result is pipes crossing beams throughout practically the entire building, internally and externally, such as the ones collecting rainwater from the balconies (areas constructed outside and additionally to the post-tensioned slabs).

Hence, despite the predetermination of parameters and even the exclusion of rules, clashes were still numerous and mostly refused. The few exceptions were found with pipes where the heights between floors between projects could be matched, running vertically through walls built of hollow non-structural blocks and making perfect sense. Apart from that, all other pipes and hydraulic elements that ran through slabs, columns, beams, and all other architectural components (doors, windows, and more) were entirely rejected, resulting in this massive negative outcome.

During the analyses of the ruleset ‘Structural versus Architectural model’, all rejected issues were due to the openings intersecting the structural components, qualifying all architectural design issues to be revised. The remaining errors were primarily due to the absence of structural elements in the architectural design, reflecting in 'orphan' components. These confrontations were all accepted in light of the structural design fitting perfectly into the architectural design, which in itself and, as previously mentioned, was converted to IFC without its structural components.

Furthering the architectonic evaluation, ‘BIM Validation – Architectural’ has shown all architectural components with mismatching measurements, for instance, doors smaller than openings. Those count as the majority of the rejected issues within the rule. Acceptance ran through most of the remaining, where minor issues as distances between components were considered non-issues. Still, the large count of accepted clashes was again in respect of the absence of structural design in the architectural, which ended up pointing out several elements that did not touch below or above, for instance, the walls, which without the structure were considered to be 'flying' within the building.

The structural design is by far the best-conceived design of all. After analysing the clashes and accurately verifying the structural model itself, it was realized that a large number of clashes indicating that components were not touching or disconnected from other components were incorrect. All structural elements, except for two clashes between beams that only partially crossed, were anchored together, with reinforced bars interconnecting them at all joints. Besides these, slabs erroneously located within the staircases and connection errors between the metallic columns of the last floor were the only main clashes rejected during the entire structural project counting the two rulesets of 'BIM Validation - Structural' and 'Intersection between Structural Components', totalling only 22 rejected results.

Consequently, after all it has been said regarding the accepted and rejected issues, the number of actual clashes per discipline have been considerably changed after the entire revision of results. Its impact on company performance is assessed later in this document, where analyses of all results have been tested. A particular previous statement is that, as this building is already under construction, most of these non-conformities that were not corrected previously are already negatively impacting the site or will do it soon, either in terms of time or cost.

7.1.4 Results Communication

In a regular project using a BIG Open BIM methodology and software like Solibri for clashes checking, many of the flaws mentioned earlier would have been fixed before the project started running on-site using the knowledge of a BIM manager and designers. The communication of such would have significantly become enhanced with the inclusion and utilization of BCF real-time collaboration and a CDE for the entire process, providing instantaneous communication between all parties to store information and knowledge for later synthesis and retrieval.

This sub-chapter assumed thus a previous use of the Solibri BCF Live Connector for the 'Residencial Âmbar’ project, which would have created a channel between a BIM manager and the designers, working as a mechanism that would report to the latter all errors to be reviewed and updated within the models while generating a vast amount of vital information and knowledge stored in the CDE. How knowledge can be managed within it benefiting the organization is explained by the final evaluation of the results in the following chapter.

The first step was to create accounts on BIM Track to use their cloud services to bridge the communication. In order to simplify the process, only two accounts were created: the first one representing the BIM Manager; and the second representing all designers. The latter, although in real cases it is commonly divided into individual accounts representing each of those responsible for the models, it was grouped up into one user to ease the execution of the analysis and avoid creating an excessive number of accounts (which would require the utilization of several emails too).

Hence, the “designers” user had to be subdivided into three distinct disciplines. Different teams were created representing the architect, the structural engineer, and the hydraulic engineer within the same profile. All clashes were reported to the same user while branching them across such disciplines, providing thus a concrete foundation for analysing each designer's performance in the end.

Therefrom the process on Solibri Office started, utilizing the BCF Live Connector tool for the communication of issues. The chosen BIM Track server was selected, thereby the ‘Master Thesis’ project, which was previously created in the web platform database to store the entire process. After the initial process, it was up to the BIM manager to report the selected problems and Solibri and BIM Track to automatically synchronize them. The interface below (figure 15) contains most of the above explanations graphically represented.

Moreover, the interface provides an entire list of issues for its user while linking the same with the exact spatial locations within the federated model. The same can be achieved via the web by utilizing the BIM Track website to fully access the same characteristics presented on Solibri – as far as the federated model is also linked to it. This interface provides excellent comprehension of issues and their placement within the project, easing and speeding the correction and understanding processes.

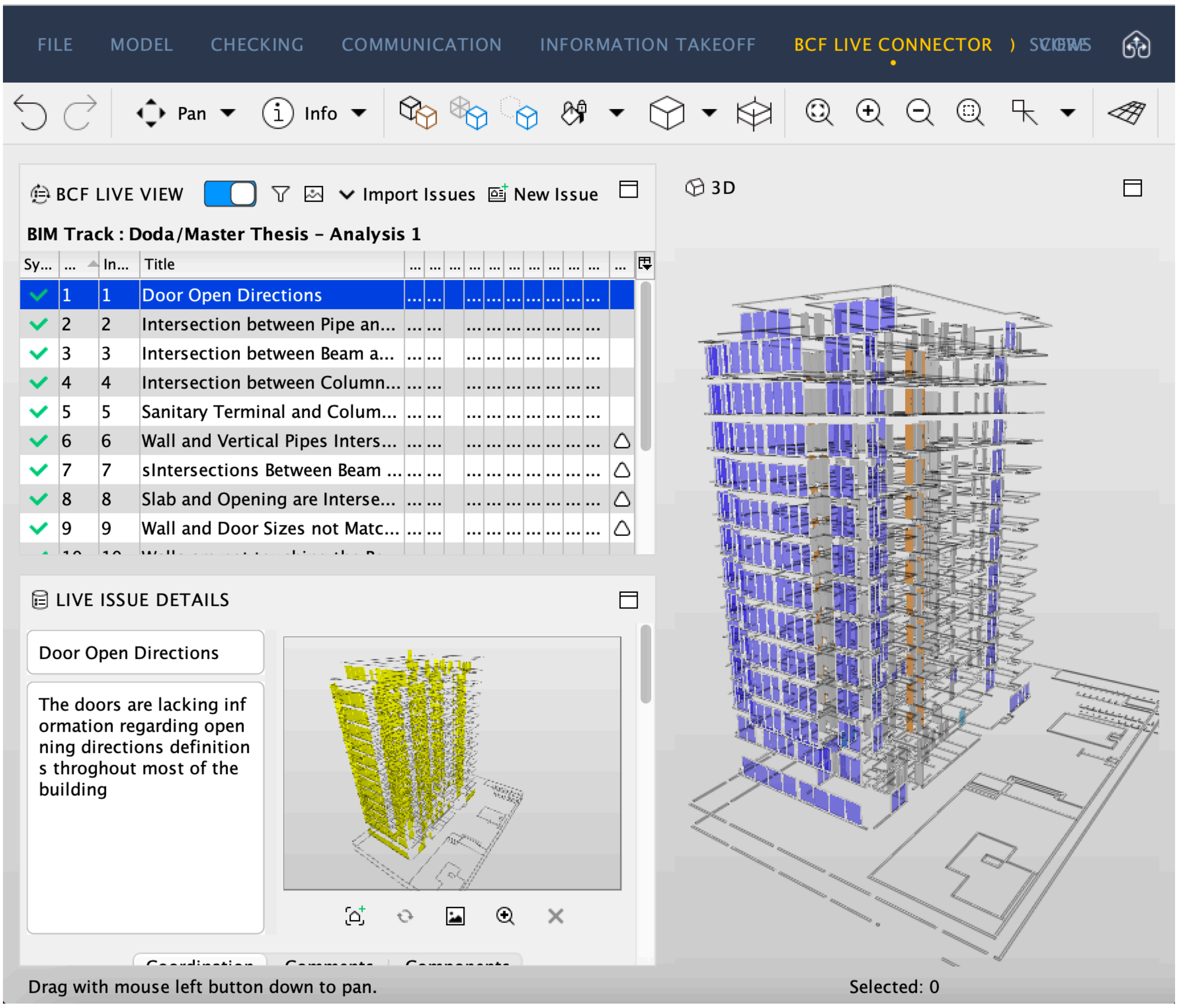

Figure 15: BCF Live Connector Interface[244]

The person reporting the clashes, in turn, has the opportunity of communicating them through a series of parameters, which help in their categorization. The range of possibilities covers sections such as name, issue description, problem view (which can be multiple and either a visualization taken from within the software or an external photo taken on-site, for instance), status, type, stage, priority, deadline, to whom the issue is being assigned, and its labels/teams (i.e., the disciplines). In addition, the detail of one problem also includes the date and time when it was created, its author and its ID. Figure 16 illustrates the whole interface of a live issue details on the Solibri Office application.

Stakeholders are depicted in 'Assigned To', represented by the designers and receivers of the information (dodaven) and by the BIM manager who has created them (EV).

[244] Own source, extracted from Solibri Office Software.

Within this parameter, the creator can select all parties that receive the problem information, excluding unnecessary stakeholders. Furthermore, when adding the participants to each project on BIM Track, the administrator and creator of such can set different roles for the users such as admin, editor and only reader. While connected to the platform, participants receive instant real-time information provided by BIM Track, calling their attention to any modifications or additional requirements by creating alerts.

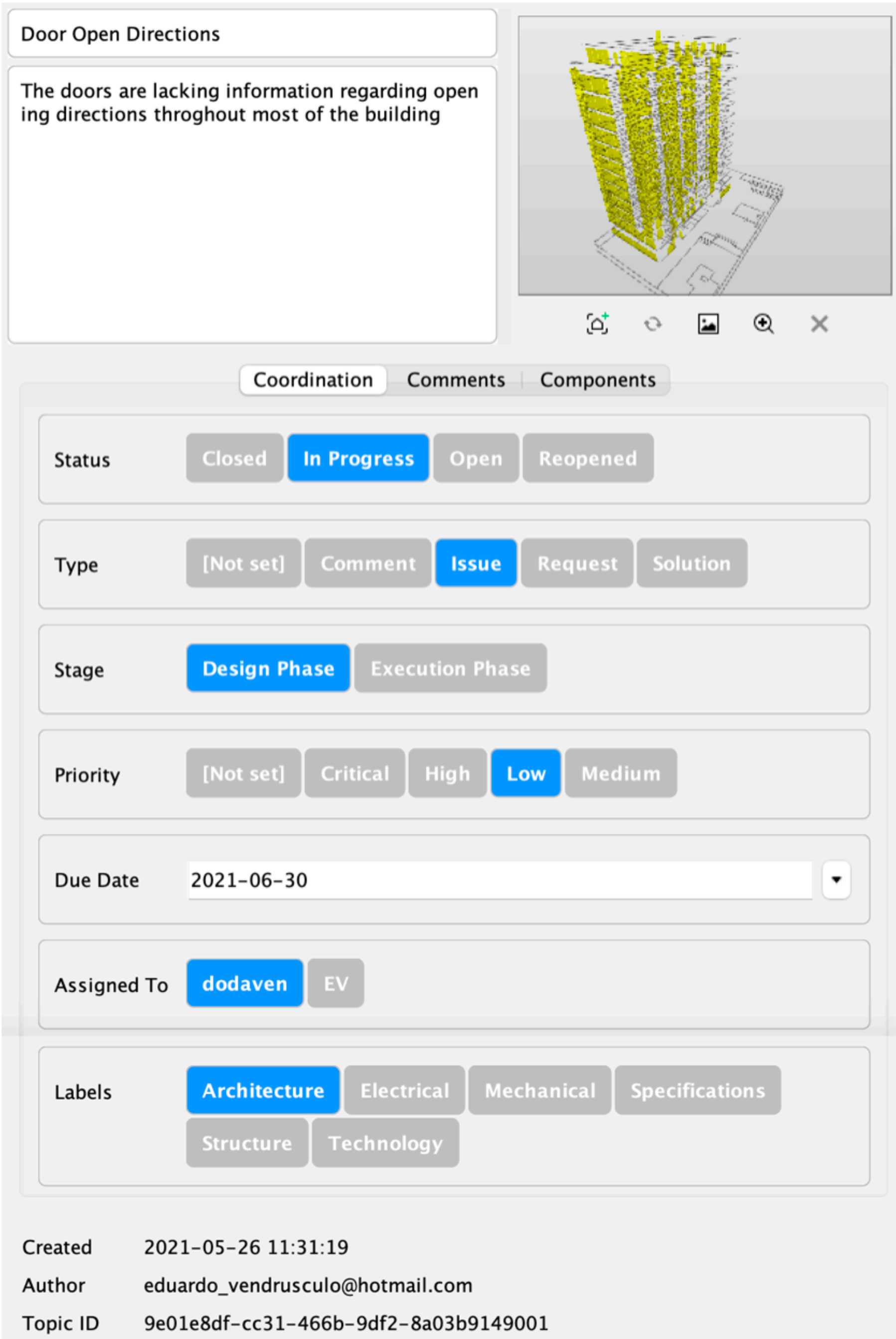

Figure 16: Live Issue Details[245]

[245] Own source, extracted from Solibri Office Software.

In extension to this depicted coordination tab, the following 'comments' one offers a dialogue box where both parties can communicate important information about corrections or simply additional facts regarding the clash. This is the core channel for knowledge exchange between parties. Within it, all addressed stakeholders can add comments either confirming the correction of issues or justifying them based on their experiential knowledge, proposing why's of rejecting such an issue or requesting a further explanation.

The downside of such a parameter is that the information generated, as well as the number of clashes of a project, is gigantic and difficult to be retrieved for further developments or to be used for the learning of newcome employees, serving primarily of immediate resolution of issues by supplying solutions based on one's knowledge at the right time. Therefore, the knowledge itself is created by externalization and internalization within the individuals participating in such communication and hardly retrieved by others - unless a person would want to read and analyse all the thousands of clashes one by one.

Additionally to the knowledge flow between specific individuals, these parameters, together with the detection of clashes, provide, from an organization's perspective, vital information to assess the stakeholder's performance in both: how satisfactorily their models have been developed; and the effectiveness with which they responded to the corrections within the deadlines. Therefore, 15 scenarios were chosen to establish a communication basis through the BCF Live Connector tool and create a framework for analysing this performance. The summed-up table below is composed of the selected subjects and some of their core information. Its resulted impacts upon one's performance were analysed in the next chapter.

Number	Issue's Name	Priority	Assigned To	Discipline
1	Door Open Directions	🔵	dodaven	Architectural
2	The intersection between Pipe and Door	🟡	dodaven	MEP
3	The intersection between Beam and Water Pipe	🔴	dodaven	MEP
4	The intersection between Column and pipes	🔴	dodaven	MEP
5	Sanitary Terminal and Column are Intersecting	🔴	dodaven	MEP
6	Wall and Vertical Pipes Intersect	🟡	dodaven	MEP
7	Intersections Between Beam and Sliding Door	🔴	dodaven	Architectural
8	Slab and Opening are Intersecting	🟡	dodaven	Architectural
9	Wall and Door Sizes not Matching	🟢	dodaven	Architectural
10	Walls are not touching the Beam	🟡	dodaven	Architectural
11	Wrong value of Property - Length: 35.05 m	🔵	dodaven	Structural
12	Slab within Staircase	🔴	dodaven	Structural
13	Column Components don't touch below	🟢	dodaven	Structural
14	Beams Partially Intercepting	🔴	dodaven	Structural
15	Slab and Metallic Column Intercepting	🟢	dodaven	Structural

From Where:

🔴 Critical Priority
🟡 High Priority
🟢 Medium Priority
🔵 Low Priority

Table 5: Summed List of Design Communicated Issues[246]

Reaffirming what has been said, all issues were channelled to ‘dodaven’ users and branched within the three disciplines. The 15 matters selected were equally picked between each one of them, amounting to 5 per discipline. An essential share of information that is not included in the table is the deadlines, which were based on assumptions and are better depicted further.

This section, therefore, provided a hint on how BCF Live Connector works in conjunction with BIM Track web-based platform. Together, they allow the company to retain most of the experiential knowledge that flows back and forth in the form of information within the central database, disregarding the future setbacks of an employee leaving the company and taking all the knowledge with him/her.

[246] Own source.

7.2 Execution Phase Data Analysis

It is throughout this chapter that the builder's experiential knowledge comes into shape. The practice of retaining the knowledge disseminated by the builder at the construction site is probably one of the biggest challenges facing the AEC industry today. The main root of the situation comes from the fact that when problems or better solutions arise on site, decisions are taken among the main involved without always going through a process of due storage of this resolution (at least in most cases), which could and should be aimed for future knowledge retrieval. Consequently, experience, the critical factor to their resolution, gets lost remaining within limited individuals.

Experiential knowledge includes mostly tacit knowledge, which is challenging to be conceptualized into rules or guidelines. This magnificent tacit knowledge residing into the master builder is either lost or transmitted among only a few other individuals through the path of socialization but hardly being externalised into the form of explicit and available knowledge. In this sense, when the builders disconnect from the company, they take with them all this valuable knowledge, representing an irreparable loss regarding future improvements in its performance.

Thus, to assess how this knowledge could be stored within the company using the BCF Live Connector tool and the BIM Track platform linked to it, this chapter provides a framework that constitutes a shortlist of assumed common lessons that the builder can bring on site. They are stored in the CDE similarly to that stated during the explanation held on the design phase analysis, using different connections and means.

The BIM Coordinator will play the leading role of collecting, synthesizing, and storing the builder's tacit knowledge in the form of explicit one. The process is done by utilizing BCF Live Connector as a communication tool between the builder and the other stakeholders while saving all the information flowing back and forth within the cloud – see figure 17 below.

Communication, therefore, is broader as when compared to the design phase, not purely being used to channel design clashes as the previous analysis but furthermore informing solutions taken on-site, requesting for execution alternatives due to different variables (or simply because data is missing), and adding comments to the project which could have led to a better result. It reinforces the failures of the design phase, the understanding between what is being designed and built, and most importantly, the remarkable contribution to the overall project by the highly experienced builder.

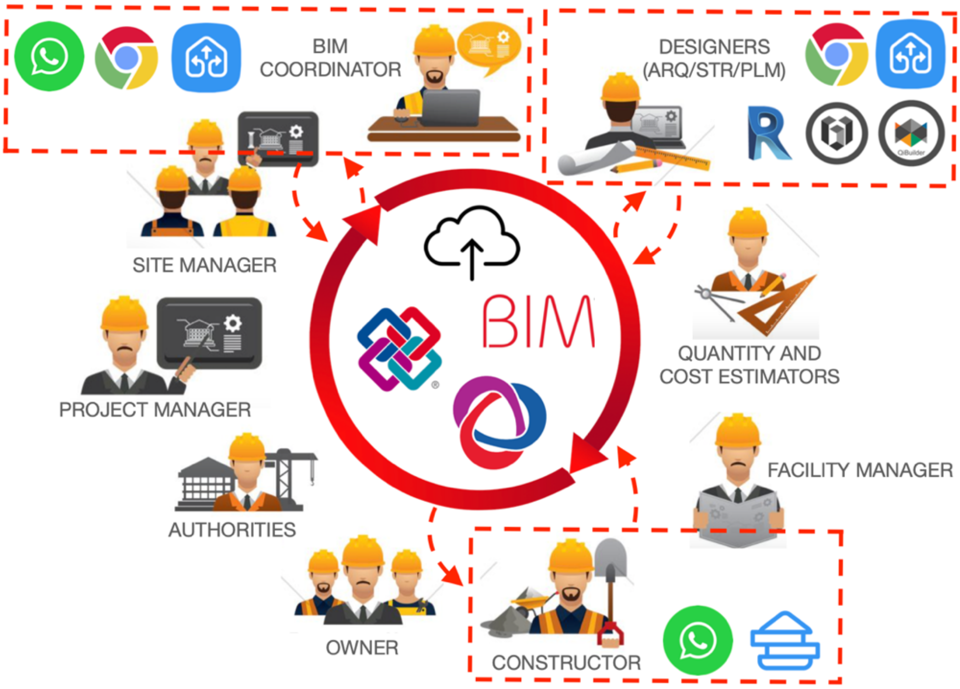

Figure: 17 Project Execution – Main Stakeholders[247]

As illustrated by the figure, communication flows between the constructor, the designers, and the BIM coordinator. The on-site builder has two communication platforms, Site Solibri and the notorious WhatsApp. In alignment with it, he/she could either communicate through the BCF Live Connector within the Solibri Site or could very well just channel the information to the BIM coordinator by using WhatsApp, the latter being responsible for its creation and dissemination.

The exchange of personal knowledge represented by the socialization method (tacit to tacit) between the builder and the BIM coordinator and the builder with other stakeholders is strongly supported by this research, given that it is one of the most effective and direct methods of knowledge creation. However, its storage and documentation must follow such an activity to be residing within the organizational boundaries to be valuable.

Nevertheless, ten scenarios were chosen, providing the aimed sample of data, listing common issues that could happen during the execution of a construction project – see

[247] Own source.

table 6 below. They followed the same procedure depicted within the design analysis, only that now they were all generated based upon the constructor perception and knowledge.

Number	Issue Name	Priority	Type	Discipline
1	Beam Moved Downwards	-	Solution	Architectural/Structural
2	Internal Slope of the Balconies not Forseen	🟡	Request	Architectural/Structural
3	Elongation of Foundation Piles	-	Solution	Structural
4	Inadequate Concrete Cover	-	Solution	Structural
5	Poor Drainage System	🔴	Request	MEP
6	Door/Opening is too Narrow	🟡	Issue	Architectural
7	Poor Facilities Allocation	-	Comment	Architectural
8	Poorly Positioned Shaft	-	Comment	MEP/Structural
9	Poor Soil Compaction	-	Comment	Specifications
10	Metal Type Replacement	-	Solution	Structural

From Where:

🔴 Critical Priority

🟡 High Priority

Table 6: Builder's Issue List[248]

It is noticed that the priority started to be chosen only for requests or issues, being disregarded when the solution was already proposed (or taken) or if it was just a comment. Furthermore, modifications can affect more than one discipline, such as the change of a pipe passing through a structural element, where then both are listed.

Whether or not to take the initiative for on-site corrections was now up to the builder and owner, taking responsibility for them as well. Only when the builder needs more in-depth details or prefers to follow the designer's recommendations that he forwards the information to the designers; otherwise, the decisions are stored directly as constructive solutions and are not linked to any other user. Furthermore, having all noted

[248] Own source.

down relieves builders of responsibility when any significant design error has been followed, rather than executive.

Detailing features for each of those issues followed the same pattern exemplified in section 7.1.4, where now the stage is fixed in the 'execution phase', and the problems are assigned either to the BIM coordinator or to the designers (always intermediated and checked by the BIM coordinator). A sample of how the execution issues were communicated through BCF Live Connector is depicted below - which in this case is a real issue/solution that has come up during the early stages of the building execution and informed by Mr Roehrs.

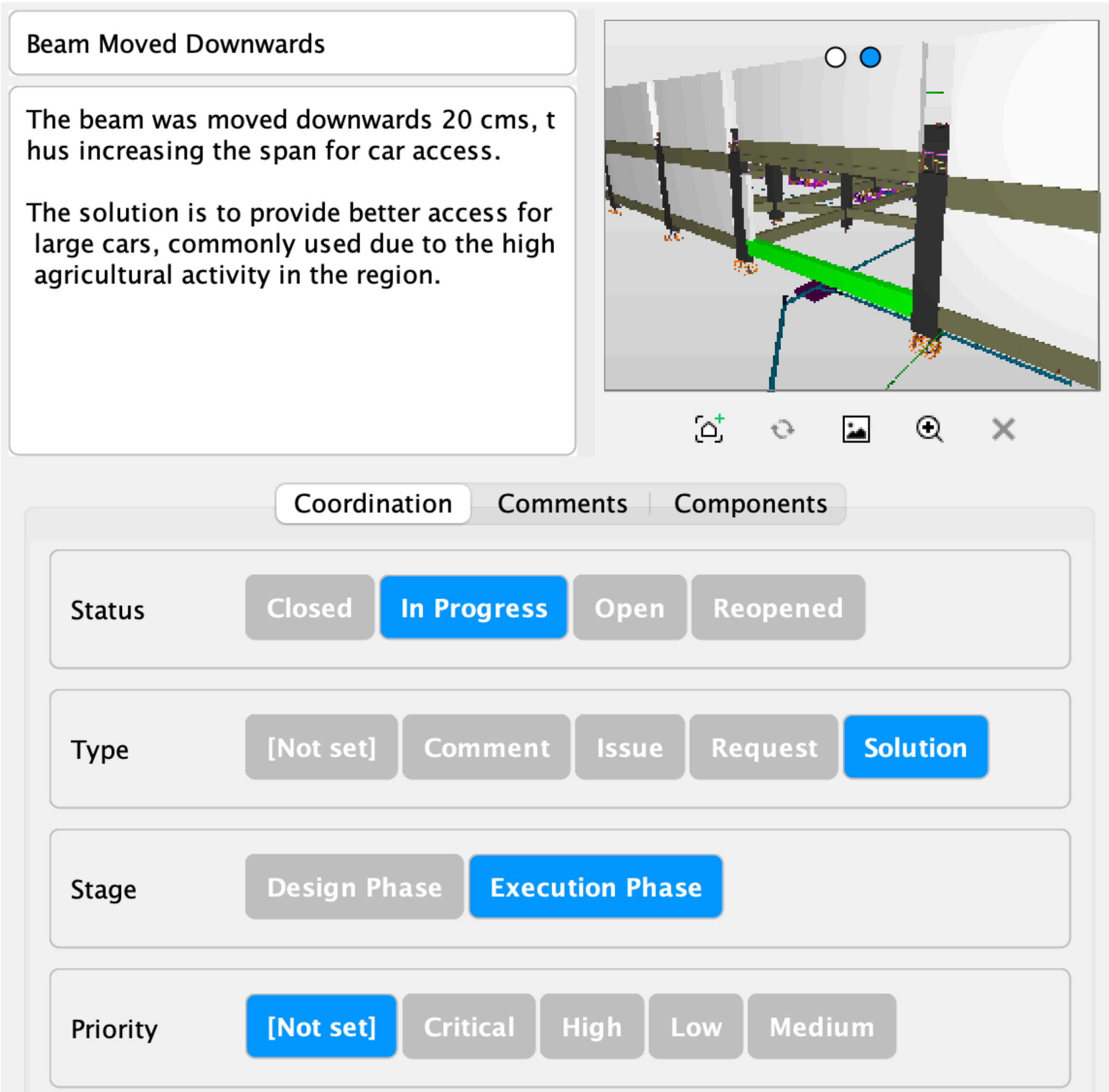

Figure 18: Communication of an Execution Solution[249]

[249] Own source, extracted from Solibri Office Software.

In describing the problem, it is clear how decision-making is based on a knowledge of execution added to an understanding of the area where the development is being erect. Essential information like this can generate small changes with great future importance to the view of the company owner, and even so, improve the performance of the designers, who, upon receiving such information, will have an improved knowledge for the execution of future projects in the same zone.

However, it is worth bearing in mind that knowledge improvement of the designers is not the main point of this research, retaining itself intrinsically to the knowledge being created for future retrieval within the construction company members, such as its executives, builder, and the BIM manager. Therefore, the primary data will always be targeted towards the direction of decision-making by the organization's executive power and the retrieval of knowledge through the replacement or addition of employers, as in future new managers and builders of BIM.

Thus, this chapter provided information on how data and knowledge storage took part through BCF Live Connector and BIM Track employing digital socialization and externalization. Considering that in the execution of a complete work, the amount of information is much more significant than that created here, this research works as an introduction to a framework that can be applied on a larger scale. The way to use it in this extension is provided in the next chapter, where data analyses from both phases are gathered and combined, leading this research to an in-depth evaluation especially focused on knowledge management.

8. Data and Information to Knowledge Creation

The primary purpose of a KM system is to enable organizations' individuals to retrieve knowledge gained and stored from past experts of the organisation[250]. Hitherto it has been seen how data and information were created based on a case study of building construction and where the content was being stored in a memory retention facility (CDE). Thereby, previous knowledge put in the form of data and information within the repository must now be gathered and consistently organized to be useful again to the organization.

The previous chapter of this research identified how tacit knowledge embedded in individuals was being transferred from one party to another while communicating issues or solutions of a given project in a sort of socialisation – although essentially occurring digitally and not physically externalization methods. This flow created a large amount of data that, by using the BCF Live Connector tool, was automatically stored within the project created in the BIM Track database.

This entire process marks the first two main steps of this research methodology: first, it identified how knowledge was being exchanged during the design and execution phases of a project, highlighted by the communication perspective and providing insights into how the BIM coordinator and builder contributed broadly to the creation of this flow by activating their experiential knowledge; and, secondly, it showed how this knowledge was being externalized within the CDE, thus being converted into data and information.

It is important to emphasize that the process of detecting clashes and communicating them is strongly focused on information management, not knowledge. Knowledge, as already highlighted in the dedicated section, is only part of the process when triggered by the BIM coordinator to identify which errors to accept or reject based on their experience with other projects or during the initial design conception by the designers, who use their knowledge in the creation of innovative models. Therefore, its development involves much more the perspective on the data and information being managed by the software and its user, identifying the project confrontations rather than the awareness of someone.

[250] Arif et al. 2008.

Now, deepening this case study and concluding the analysis with the presentation of its results, this research performs the last two essential steps to affirm BIM as a knowledge management tool: the ‘knowledge construction and organizational knowledge’; and the ‘knowledge retrieval'. The first was structured to support the latter, guaranteeing access to the stored knowledge and the ability to access it. Hence together, they represented how data and information finally became a valuable knowledge asset for the organization.

8.1 Knowledge Construction and Organizational Knowledge

Knowledge construction exposes how new knowledge is created based on the previous individuals’ knowledge stored in the database. All data were categorized in a way in which knowledge could be used from an organizational perspective to drive optimised performance, being therefore systematized to generate knowledge for both: corporate executives, focused on decision-making in future developments; and individuals within the organization, who could benefit from the knowledge being stored by former experienced professionals, boosting their performance and consequently the organizational one - avoiding the knowledge lost.

Knowledge that was previously invisible within individuals is now exposed in the database. Its construction was firmly based on the organizational model proposed by Walsh and Ungson (1991) described in section 3.3.1, where communication through the BCF Live Connector represents the decision environment followed by the acquisition of information by the company through its storage in the database. Subsequently, the information is made available for retrieval and dissemination. The knowledge that systematizes everything from the initial integration of data and information to its ultimate retrieval is the link behind it all[251].

The parameters offered by the BCF Live Connector have provided the organization of data since the beginning of communication. When identifying whether the data was generated during the project design or execution, a large part would already be deployed in these two main construction phases. By narrowing down even further through the disciplines (labels) and categories of types, it is possible to know precisely everything between the problems, solutions, comments, or requests that are being

[251] Arif et al. 2008.

addressed for each of the design areas that a project involves – allowing a performance analysis of each designer.

In a real standard project, such represents a large amount of data and information, all stored in the company's CDE or database, but worthless when not appropriately organised. Here comes the duty of the BIM coordinator again, who was a critical factor in previous data creation and analysis processes and is now again synthesizing that data so that knowledge can be reached within the organization.

The process followed two paths. First, it has played an informational role; the data and information content housed in the CDE had contributed to efficient and effective decision making within the organisation. Second, organisational memory fulfilled a control and distribution function by reducing the transaction time and costs associated with implementing organizational knowledge to newcomers.

8.1.1 Knowledge Supporting Decision Making

The first knowledge brought by analysing data and information, especially regarding the clash's detection (which was a complete analysis of the real models), was upon how the designers have performed throughout the project. By arranging all the data in the form of charts and synthesised information, the BIM coordinator would have provided the organization executives with valuable knowledge for defining whether or not to maintain the same designers for future projects and lightening which actions should be taken.

The first primary evaluation is made upon the clashes results based on table 4, indicating the values after the revision. The pie chart below created based on such values illustrates the percentage with which each discipline/designer contributed to the whole sum of design issues. The issues detected during the execution phase are not part of this analysis as the building is still running and data is still incomplete, and therefore the values were assumed to propose other evaluations.

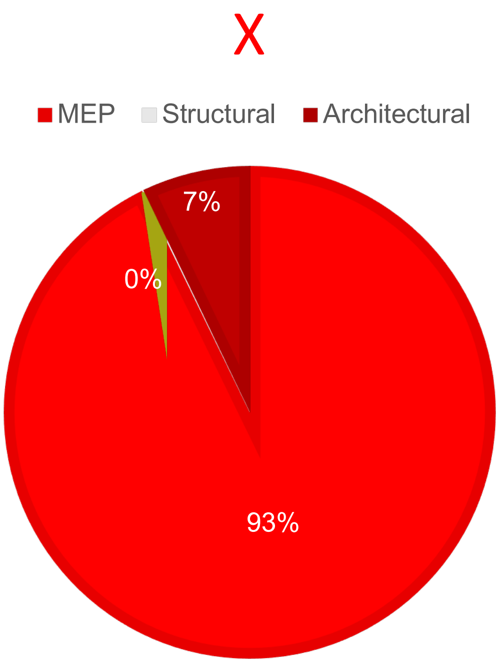

Figure 19: Rejected Clashes Percentages by Disciplines[252]

As we shall see on the chart, the structural design, although rounded to 0, represents 0.13% of the total rejected classes and therefore only 22 clashes, followed by the architecture gathering 7% and 1215 clashes and the MEP design resulting in 93% and 15901 conflicts. It gives the first hint upon the time impact the miscommunication and misconception of models must have caused during the design phase. Regarding the vast selection of clashes, the percentages reflect an appropriate comparison of the designer's performance.

Now, in a much-simplified, prototypical form and line with the 15 clashes selected during the design phase plus the ten assumptions created during the execution phase, it is possible to extract directly from the BIM Track web platform some other information already synthesized in the form of dashboards to help decision-makers to evaluate the designers' performances.

The first image is related to design and execution issues reported in the BCF Live Connector tool stored in the BIM Track database - 25 cases in total. This helps to create an overview of how the project performs in terms of how many issues are still

[252] Own source.

open and to whom they are assigned and highlight each designer's responsive performance.

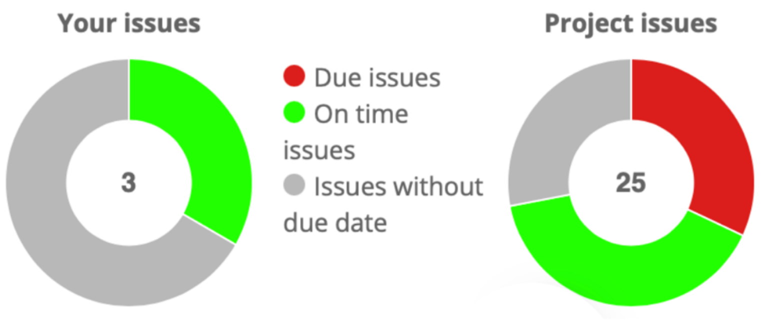

Figure 20: Response Performance Evaluation[253]

The issues without a due date are the solutions or comments proposed by the site builder, which had no necessity of deadlines. Everything else is included in the response time assessment and can be assessed by selecting only a particular discipline rather than the project in general - as represented in figure 20. Such would narrow down the evaluation of specific designers and models.

Therefore, while such charts provide the designers with an overview of their duties, it offers relevant information for company executives and BIM coordinators to evaluate the performance of the designers, creating thus knowledge upon concluding how to proceed with each responsible. The performance upon responding to issues and the quantity of the problems a design is responsible for can tell a lot about one's behaviour within a project.

The following three images extracted from the BIM Track metrics portray another synthesis within the platform where issues are subdivided into their phases, types, and disciplines. In a user-friendly and straightforward way, they allow the project's fundamental values to be effortlessly read by any user involved and provide an excellent overview of its development.

[253] Own source, extracted from BIM Track web platform.

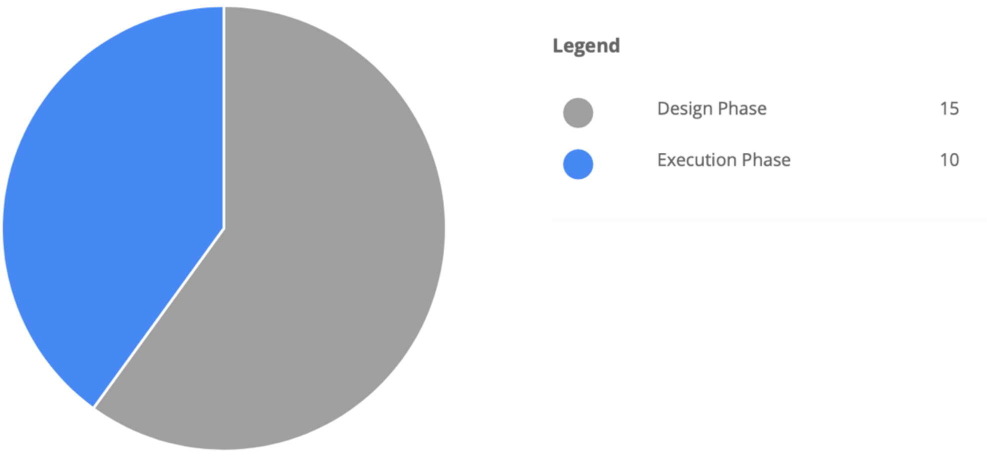

Figure 21: Project Issues Classified by Phases[254]

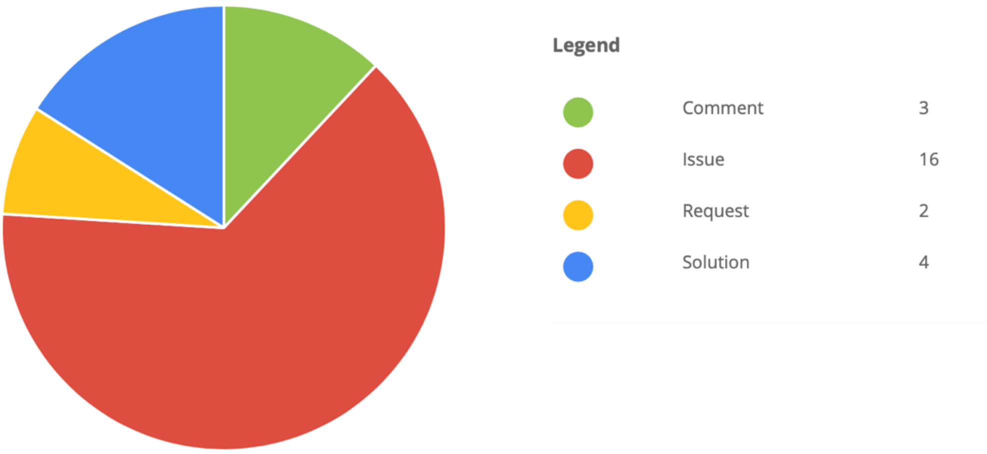

Figure 22: Project Issues Classified by Types[255]

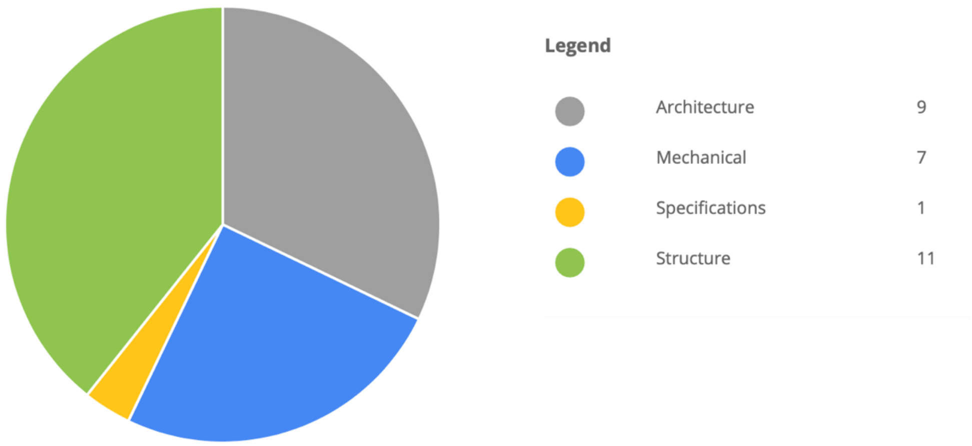

Figure 23: Project Issues Classified by Disciplines[256]

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[254] Own source, extracted from BIM Track web platform.
[255] Own source, extracted from BIM Track web platform.
[256] Own source, extracted from BIM Track web platform.

The first chart represents a view that often falls to basics knowing that issues occurring during the design phases commonly will hold a more significant number of issues when compared to the execution – mainly when in-depth compatibilization between models and clashes analysis is performed. Nevertheless, its numbers are essential for comparisons between past and future jobs, making use of the area and hardship degree relation of the project with its errors per phase to produce company's performance evaluations upon whether the achievement of improvements throughout projects is happening or not.

By clicking in one of these chart areas, the analyser is directed to an automatic report containing the related issues' complete information. Furthermore, when selecting a particular issue, a section provides the entire communication flow history between the parties, made by a provided tab of comments and attachments. A kind of chat is created by generating these comments, exposing all the knowledge coming from both parties stored as information. Thereby, when more specific information on how actions were taken in past projects is needed, it is very likely to be found in such dialogue boxes.

That said, when a decision between the designer and the builder is not possible, or if in any case, it requires the conclusion of the investor/owner, the latter can readily access the matter by tracking and accessing the issue, which always holds a number as well. When investigating it in BIM Track, the developer will come across all the necessary information about the issue and the knowledge flow of the parties involved, generating his/her knowledge about the situation, thus clarifying in which direction to proceed.

Following the methodology proposed by this research, this would be the key example of how to use the knowledge and information filled in databases to supply the right people at the right time in a much more interactive and visible way, where images and the 3D design itself indicate errors and a visual approach to the discussion without the real need to have everyone physically involved on the job site.

By receiving all this information in charts and tables, the company executives convert it into meaning, reflecting into action and thus knowledge, thus contextualising the excessive amount of data generated throughout the project lifecycle. Therefore, executives are not expected to read and remember all the clashes and comments, dialogues within their creation, and so further, but they will always come across some key inputs when asked to make an immediate decision. In the same way, when the project is complete, and conclusions for a future project are needed, they will be faced with some significant supportive takeaways.

8.1.2 Knowledge Retention within the Company

The step of retaining the knowledge within a company is one of the significant assets of knowledge management. As already seen, the builder and the BIM coordinator are the main key focus through this research, and it is their knowledge that will be aimed to be captured and retrieved.

The capturing was made clear by chapter 7, where the identification of issues among the flow of comments and insights would be simulating this knowledge exchange while storing everything within the database. It is shown how this entire content can somehow be beneficial for the newcomers and other company members, spreading the knowledge of builders and BIM coordinators throughout different levels. It provides both the avoidance of losing knowledge in the case of the disconnection of aforementioned company members and the easier replacement when made necessary.

Solibri and BIM Track worked as the effective tool where everything was being stored, and the database/CDE is the main asset where all knowledge transfer strategy is boosting. Nevertheless, without the motivation and incentive for members to share and use the platforms to communicate, the entire purpose of this methodology would have no sense, and the process would never exist. So, when BIM coordinators and builders are pushed to use and expose their experiences by communicating within this system, everything comes to form.

In this sense, the BIM coordinator, placed at the centre of the entire communication flow, would be requested to catalogue all the main issues/learnings originating from the party’s communication throughout the project. A selection process could do that before archiving the problems being solved. He/she would have to select the main issues that either took a deeper dialogue, provided an entirely new personal experience, or required deepening the company's structures to be solved.

Every issue reported on Solibri/BIM Track is archived within the database when solved, being available for whoever needs to re-check them later. By creating a new type of issue, called ‘Key Learnings’, the BIM coordinator could, by analysing the knowledge level of the issues being an enclosure, classify it as a crucial issue for knowledge retrieval before archiving such.

The process would synthesise among all the thousands of issues only the most valuable ones for further learning to be applied in future projects, where a significant part of the company’s culture upon decisions would also be within. They would furthermore contain precious experiential knowledge of the BIM coordinator – during the design phase – and the constructor – during the execution phase – exposing the why’s for such modifications based on what they were being taken.

In addition to it, the BIM coordinator and the constructor would have the total freedom and incentive to add key findings during both phases to this group type of issues. They would be firmly requested to add directly to the ‘Key Learnings’ category their major conclusions about jobs or the phases in general, adding thus priceless contribution for the final report and presentation. The process would be then made open to necessary company members through its database.

As a sample for this framework, the same 25 total issues were taken, and the process was undergone. Appendix D shows how the representation of such would occur after archiving all the subjects and selecting the key ones, where three issues were chosen as ‘key learnings’ plus an additional comment introduced by the BIM coordinator regarding the design phase completion. The report represented within the appendix was built on selected parameters thought to be appropriate for its confection, and it replicates in a short scale exactly how a real-life report following the proposed framework would look like.

Furthermore, charts can be beneficial when working on the BIM Track platform, and as it might be seen by the figure below, the phases are distinguished between each other, which could still provide reports or files designated explicitly to the use or evaluation of each phase execution individually. Disciplines might also be tabbed aimed at reports creation, helping to extract knowledge directly from specific subjects.

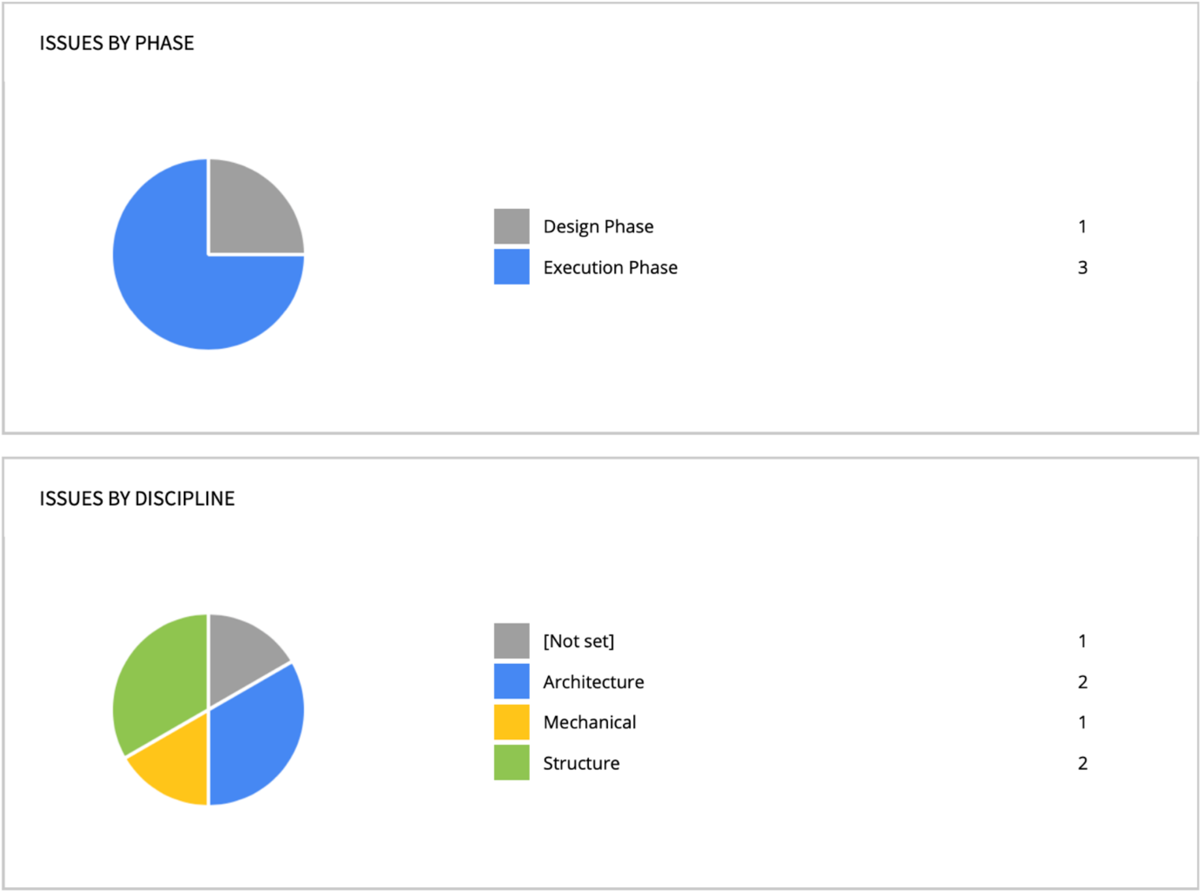

Figure 24: Phase and Disciplines 'Key Learnings' Charts[257]

The issue number 23 dialogue box below extracted from the report exemplifies briefly how the dialogue would flow between the parties – in this case, the builder and the plumbing designer. Next, figure 25 depicts a vital comment made by the BIM coordinator regarding the project design phase, providing information about one of the main failures during the case study analysis.

COMMENTS

USER / DATE	COMMENTS
Designers R 7/1/2021 9:22 AM	The position for such a shaft is selected in accordance with the reduction of the excessive consumption of pipes in the work and thus is still considered the best option.
Eduardo Vendrusculo 7/1/2021 9:26 AM	The justification for such a position still has no value compared to the increase in on-site work for its realisation and should not be repeated in future projects.

Figure 25: Issue Number 23 - Dialogue Box[258]

[257] Own source, extracted from BIM Track web platform.
[258] Own source, extracted from BIM Track web platform.

26. Hydraulic Project Unevenness

Description: The unevenness of the hydraulic project in comparison to the others, despite having created so many errors, also generated a greater use of time to be solved, which resulted in the delay of the project during the design phase.

Figure 26: BIM Coordinator Final Comments[259]

Boxes and comments like this may stretch for many lines and carry within themselves necessary knowledge from designers, builders or whoever is involved within the project. It provides excellent insides for managing the project to understand better all the parties' views involved and how to deal with them. For a newcomer with no experience within the company, a knowledge-based report provides a valuable intro to how decisions are carried out during project execution and how the BIM coordinator places himself/herself within it. A builder with no experience within the company would also profit from the learnings left by the previous constructor, providing them with strong feelings on how the decisions are taken and how to report and act upon them.

The company's owners and executives provide a conclusive report about all the main issues, flaws, especially learnings they could carry out after the project closure. They can analyse everything being highlighted by the BIM coordinator and the constructor during the project phases execution, building their awareness upon forthcoming projects possible inaccuracies and creating a solid basis for selecting future projects deliveries and personnel. The report could be stored within the company's database or transmitted by any other information technology like email to significant stakeholders.

These actions ensure that valuable knowledge/information is remaining stored within the company. Furthermore, the information being produced daily and readily accessible to anyone means that if at any time a BIM coordinator or builder would have to get away from the company, even during project execution, others could also replace it by following and tracking the steps that have been taken so far, despite the overwork that would require.

In this sense, knowledge would be prepared to be transferred in the future, helping the employees exit smoothly and leaving a solid legacy of facts behind them. The new contractors or employees, having access to this storage, can learn and reply to much

[259] Own source, extracted from BIM Track web platform.

of the past actions that have been taken within the company. Moreover, the organisation itself would have to be always liked to the entire process, permitting thus the ability to select and allow access to the stored knowledge when necessary.

The mechanism represents a continuous/ongoing process strongly marked by knowledge retention and distribution. The construction of this knowledge derives from an individual's prior knowledge and experience, which includes mainly: cultural, personal, and tacit knowledge. This knowledge, sometimes 'invisible', can never be ignored. It must be instigated and extracted from experienced employees to become meaningful. In doing so, the company would enter a knowledge-centred approach in which all this experience becomes central to its success.

8.2 Barriers to Uptake

For some new ideas or methodologies to be implemented, some barriers are commonly expected. As the implementation of knowledge management directly involves the organization and the people embraced by it, it is natural that required changes and upgrades also comprise both. The main advances required are listed and explained below.

Acceptance of BIM

First and foremost is the acceptance of the benefits and uses of BIM technology within the AEC industry and, therefore, within organizations themselves, which still lacks substantial compliance among companies and developers while advancing faster every year. By accepting and implementing BIM within the company, this proposal will have space to be put into action.

Experienced BIM Manager

A solid and experienced BIM manager, aware of the company's proposal concerning knowledge retention and management, is the primary human element after the acceptance of the methodology by the company. As acknowledged throughout this paper, the BIM manager is the key factor from the earlier phases to the latest, providing the flow of all knowledge with structure and meaning. Therefore, without an outstanding professional, the methodology would fall apart in its conception or give empty results no performance improvements.

Infrastructure Supporting Real-time Connection

In addition, for the project to work in real-time on-site among its stakeholders, some important hurdles to overcome. First, an infrastructure that provides wireless connection and on-site phone signal coverage is necessary. Second, the company would have to provide adequate hardware, such as smart devices, to key individuals involved in communication. Along with the hardware comes the acquisition of software and the keys necessary for the methodology to work. Such points are crucial regarding the quality of the information flow, thus providing harmonious communication between the parties instead of causing more headaches for their operators.

Financial and Time Investment

The central aspect that will involve the company in accepting this methodology will be the time, money, and training necessary for its success. The company would have to be willing to invest in these three for the process to be effective and would still have to expect the long-term benefits that would accrue from their application. Its knowledge and management will likely increase the company's competitiveness in the market, but it must be analysed and recognized as such to be viable. It takes time to implement the methodology and execute it during the project, and so often, the advantages and time saved from design and execution improvements by avoiding making the same mistakes repeatedly are overlooked. If the company, at any time, finds that knowledge management will not bring it any advantage, in the short or long term, the idea will mistakenly never take off.

Incentive and Willingness of Professionals

Finally, the general transformation of knowledge through individuals presents solid social barriers, such as reluctance on the part of individuals to share their experience, reluctance on others to use and agree with it, and hesitation of some professionals to collaborate with other experts. The willingness of all professionals to share, use and disseminate knowledge is essential for any type of knowledge management purpose that involves tacit and experiential knowledge. The company must facilitate the sharing process and require its professionals to comply with the use of the platforms, making them understand the benefits of collaboration between stakeholders and the effectiveness of such methods. Only by involving all stakeholders to believe and contribute to the idea, their knowledge, that of the company and the newcomers can finally be improved, reaping the gains of this implementation entirely.

9. Conclusion

This work was set out to propose, as its title indicates, the "Development of Knowledge Management upon the use of BIM Collaboration Format". The progress of this research was thus structured accordingly to this theme, aiming to embrace the fundamental topics so that the combination of these two matters could blossom into something constructive and positive for the field of architecture, engineering, and construction.

Therefore, the approach has led to the extensive interrogation and explanation of knowledge management, specifying its inaccuracies by pointing out inabilities to capture, manage and share tacit knowledge within organizations and projects. The analysis of the problems involving KM naturally linked the subject with the utilization of ITs, which notably eases the capturing of knowledge whilst providing an enormous enhancement towards its storage and sharing, especially regarding the use of data clouds. However, the use of ITs led to an even thinner line when differentiating information management from knowledge management. Its distinction is fundamental so that we do not fall into the fallacy of thinking that knowledge is being provided when in fact it is just information. This factor was undoubtedly the most significant hardship during the development of this research, resulting in a chapter specially designed to explore information management and its systems while the subject was directly confronted with knowledge.

The BIM methodology is today the leading digital development for the implementation of IT and IS in the field of AEC, allowing participants to achieve immense degrees of collaboration during the execution of a project. In this sense, its application to implement knowledge management in a project has proved entirely rational, and hence the use of the BCF format, which, combined with real-time communication software and a CDE that stores and manages all information, offers a broad gateway for knowledge to be synthesized and extracted from the entire process of communicating project issues and solutions. The remaining problems were still interoperability, information overload during a project and, above all, the encouragement of communication between professionals.

From there, to analyse the capabilities of the real-time application of the BCF, an experimental project based on a case study was formulated, contributing to pointing out how to solve the KM challenges in AEC projects. The experimental design, along with the literature review, leveraged the answer to the five research questions proposed by this article, involving the combined use of KM and BIM/BCF in the AEC industry. Inputs and outputs were as closely linked to a real-world context within the field as possible, providing a real application of the method and not just theoretical content.

The product was an experimental setup based on the execution of an actual project, where problems were approached and evaluated for their relevance and meaning in practice, derived from factual information and assumptions. Moreover, the results are interrelated throughout the analysis with the SECI model of knowledge creation in the context of AEC, highlighting the processes that constitute the knowledge creation mechanisms in all stages of the development of the case study, shaping a spectrum between tacit and explicit knowledge and their methods of creation.

Following the rising and growth of this research, we conclude it by re-evaluating the five research questions, summarising their values and findings.

9.1 Research Questions

What means Knowledge Management and why it has become such a core field?

Knowledge management strongly involves human and organizational behaviour within corporations, developing directly concerning tacit and explicit knowledge. The subject has become such an acclaimed subject within organizations due to its logical and positive outcomes, providing a tremendous competitive advance in the current markets for the companies that implement it. It highly supports the enhancement of individual and organizational knowledge.

What is Information Management and how it differentiates from Knowledge Management?

Information management is simply the administration of the entire flow of information, either in AEC or in any other field of application. It is entirely relying upon data and information in the form of numbers, facts, etc. IM is technologically driven, meaning that the software composing the BIM methodology, for instance, are in their majority information management systems, providing the “know what” through explicit information easy to identify and share. On the other hand, knowledge management deals more boldly with people and the knowledge creation and exchange processes between them, providing the experience of “know-how” relying strongly on tacit knowledge challenging to copy, identify, and share.

Can BIM/BCF be considered a Knowledge Management System? If so, how?

First, BIM is a methodology, and BCF is a format for exchanging information that facilitates stakeholder communication throughout a project. Hence, they are not considered systems per se and therefore cannot be assigned as a KMS. However, its application through software that provides real-time communication linked to a cloud-based environment, as seen during this research, can bring many benefits for the creation, retention, and distribution of knowledge within AEC. Thus, when correctly applied following some standards that lead to knowledge analysis, these platforms can become a genuine source for knowledge management. Conclusively, a range of software within BIM may be applied as a KMS, but it is a fallacy to claim that BIM or BCF are systems.

How can BCF be used as a real-time tool enhancing experienced-based knowledge during design and execution phases?

BCF used in software that provides real-time communication between stakeholders provides a magnificent interface for knowledge exchange and storage. While professionals discuss issues using communication platforms themselves, whether, in the design or execution phases, all their knowledge is automatically stored within the CDE, providing, in addition to knowledge retention, a complete report on how problems were handled and decisions made.

During the design phase, mostly the designers and the BIM manager discuss project flaws and possible improvements before execution. In contrast, in the execution phase, the builder and his experiential knowledge are intensely activated by diverging the design with the as-built methods in the works. Consequently, the knowledge exchanged during the two phases dramatically improves the current project and the forthcoming ones. Furthermore, when synthesized, such knowledge provides essential takeaways for decision-making and newcomers who understand little or nothing about the methods or the corporate environment.

What practices and methods would make such a union effective and widely used within the branches of Architecture/Engineering/Construction projects?

First, organizations within the AEC environment will have to understand and accept the benefits emerging from using BIM within its framework and, therefore, the improvements that knowledge management can bring to its entire framework. From there, it is a matter of time, cost and, above all, staff encouragement to share their knowledge with other professionals through the methodology proposed here. KM is intrinsically dependent on people and their willingness to collaborate; without their incentive and common sense, the union of both matters will never become effective. AEC companies should provide an adequate assessment of the improvements arising from the merger of KM, BIM and BCF so that their execution can leverage the organization's performance and materialize in the industry.

9.2 Limitations and Further Recommendations

Firstly, it is evident that an even more in-depth literature review on the subjects could have been provided. Today, with the accessibility to information that the internet offers us, the sources are inexhaustible, and we do not have enough time to read, analyse and synthesize them all. Along with it, despite knowing BIM and some software within its range, I had little understanding of what knowledge management and BCF means. Furthermore, the application of BCF through a live communication tool was also entirely new for me, meaning that I had to delve even further into these subjects I had little or no knowledge of, starting the research from the primary stages of understanding the matters. On the contrary, this work would have proposed much more complex and concrete objectives if it had emerged from a solid knowledge base.

Secondly, most criteria of this research were stipulated by me, being them at the parameters of rulesets for checking models or communicating the same through BCF Live Connector. In someone else's view, these criteria could be created differently, generating specific results for other purposes or just categorizing them at different organizational levels. Organizations diverge among their structures as well, a fact that would contribute to some further changes according to their needs and goals. Therefore, as the software enables the user to create different parameters and categories, the possibilities go way beyond the clash communication, which is the main feature of BCF Live Connector.

Nevertheless, beyond the personal limitations, this research has also led to many new questions and proposals. The applicability and monitoring of this framework in a real-case study, from concept to end, would enhance its outcomes greatly. Even more, it would require an intense and daily analysis of all the knowledge that flows through the life cycle of a project, prompting a company's desire to be willing to analyse its benefits and losses.

Moreover, software developers could focus on add-ons where knowledge management linkages could be part of their interface, providing a direct channel between the project, the organization, the software, and knowledge, as it happens for communication through the BCF live connector. It would significantly increase the direction of knowledge capture and distribution, where the section specialized in its management would be linked to the software itself holding clear-cut settings turned to its success.

However, there is no extent for the evolution of software and IT within the branches of KM and BIM. Beyond improving the capitation through BCF, many other proposals using different tools to capture knowledge may be used. The analysis of additional software and tools are thoroughly recommended for the evolution of the field, encouraging both organizations and developers to use their instruments as further as possible to develop increasingly better, more direct and efficient software.

Following the tendency of this research towards the SECI model processes, it is worth highlighting that there is still much more about this subject to be deepened. The model has been present for years in the constructive process of knowledge management and can still offer much more to the field if coupled with today's technological and scientific advances. Investigations upon its use by tools as BCF real-time communication through case studies proposing the development upon the four processes in real-world AEC contexts is a must when envisioning the long-term applicability of KM.

Conclusively, through the analysis of BCF real-time communication within a BIG Open BIM methodology in the AEC context, I hope this paper will generate a new perspective upon the role and usage of KM within the AEC industry and likewise its software applications. The potential of KM is infinite, and with the development of IT at an increasingly accelerated pace, its application benefits leave an optimal future expectation, where knowledge will reach unimaginable levels by organizations and individuals.

Declaration of Authorship

I hereby declare that the attached Master's thesis was completed independently and without the prohibited assistance of third parties, and that no sources or assistance were used other than those listed. All passages whose content or wording originates from another publication have been marked as such. Neither this thesis nor any variant of it has previously been submitted to an examining authority or published.

Berlin, 30.07.2021

Eduardo Vendrusculo

Consent of publishing the Master`s Thesis

English translation for information purposes only.

Publication of the Final Thesis

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Hochschule für Technik und Wirtschaft Berlin
University of Applied Sciences

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Study Programme: International Master of Science in Construction and Real Estate Management

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29.07.2021

Date and Signature of the Data Subject

Appendix

Appendix A

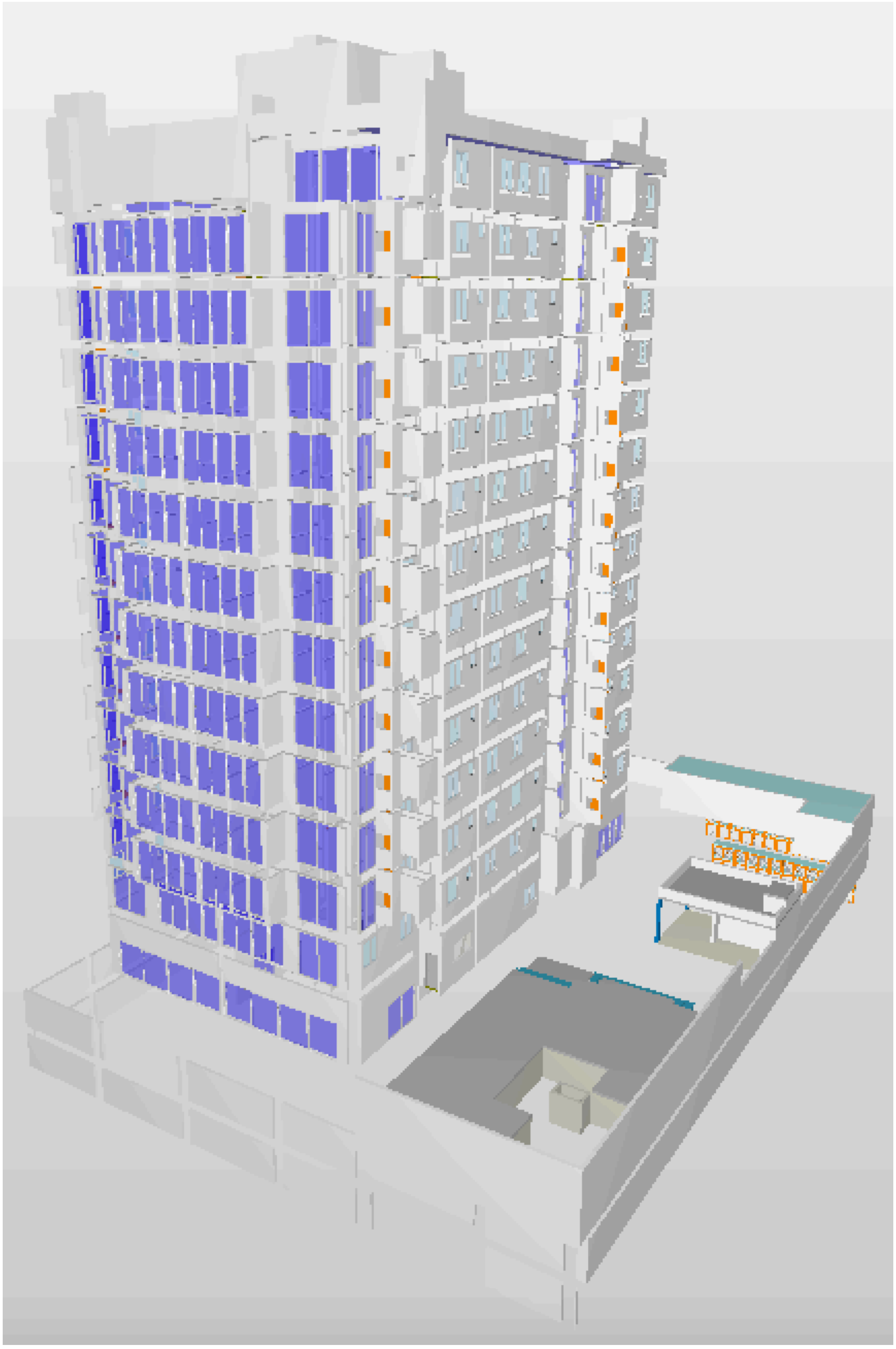


Figure 27: 'Residencial Âmbar' Architectural Model – with Extraction of Structural Components[260]

[260] Own source, extracted from Solibri Office Software based on data provided by Mr Roehrs 2021.

Appendix B

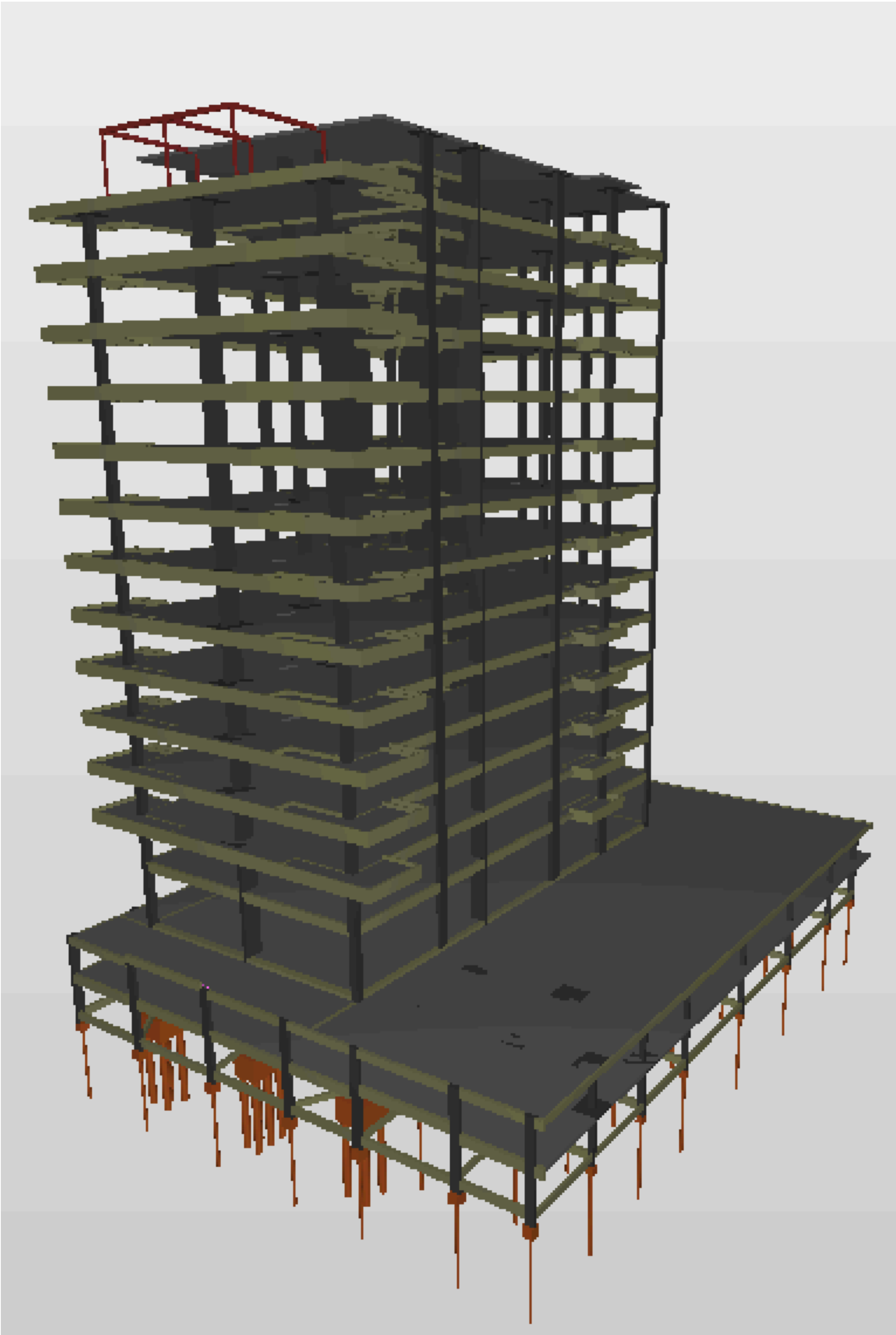


Figure 28: 'Residencial Âmbar' Structural Model[261]

[261] Own source, extracted from Solibri Office Software based on data provided by Mr Roehrs 2021.

Appendix C

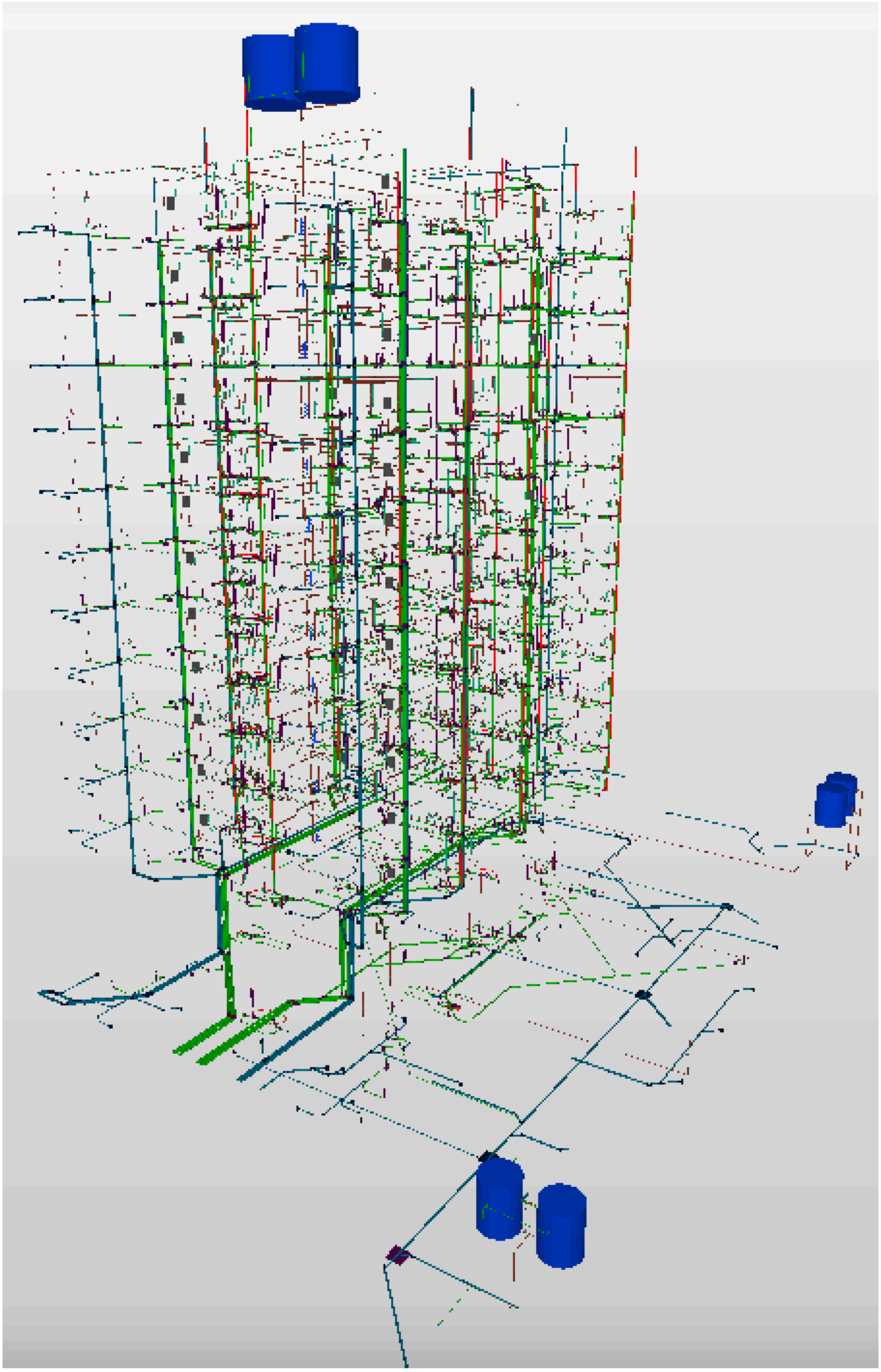


Figure 29: 'Residencial Âmbar' Plumbing Model[262]

[262] Own source, extracted from Solibri Office Software based on data provided by Mr Roehrs 2021.

Appendix D

Final ‘Key Learnings’ report.

Doda - BIM Track® 01.07.21, 11:55

Doda

Master Thesis - Analysis 1
Issue Report

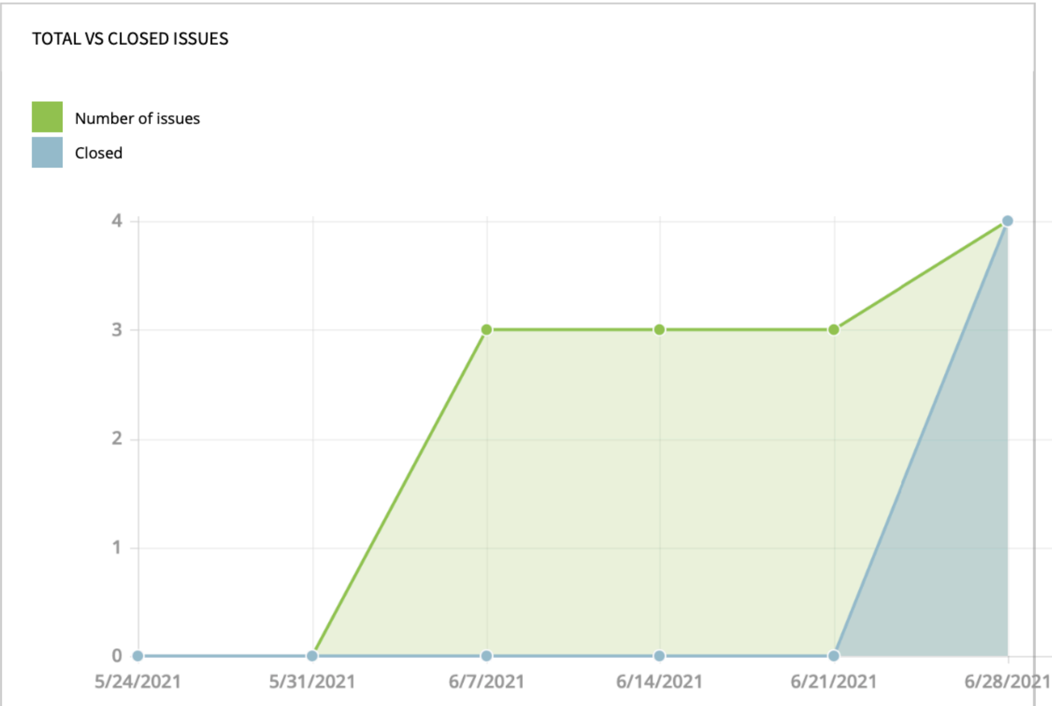
Printed by Eduardo Vendrusculo
Date : 7/1/2021 9:47 AM UTC

Summary

Total project issues : 26

Total printed issues : 4

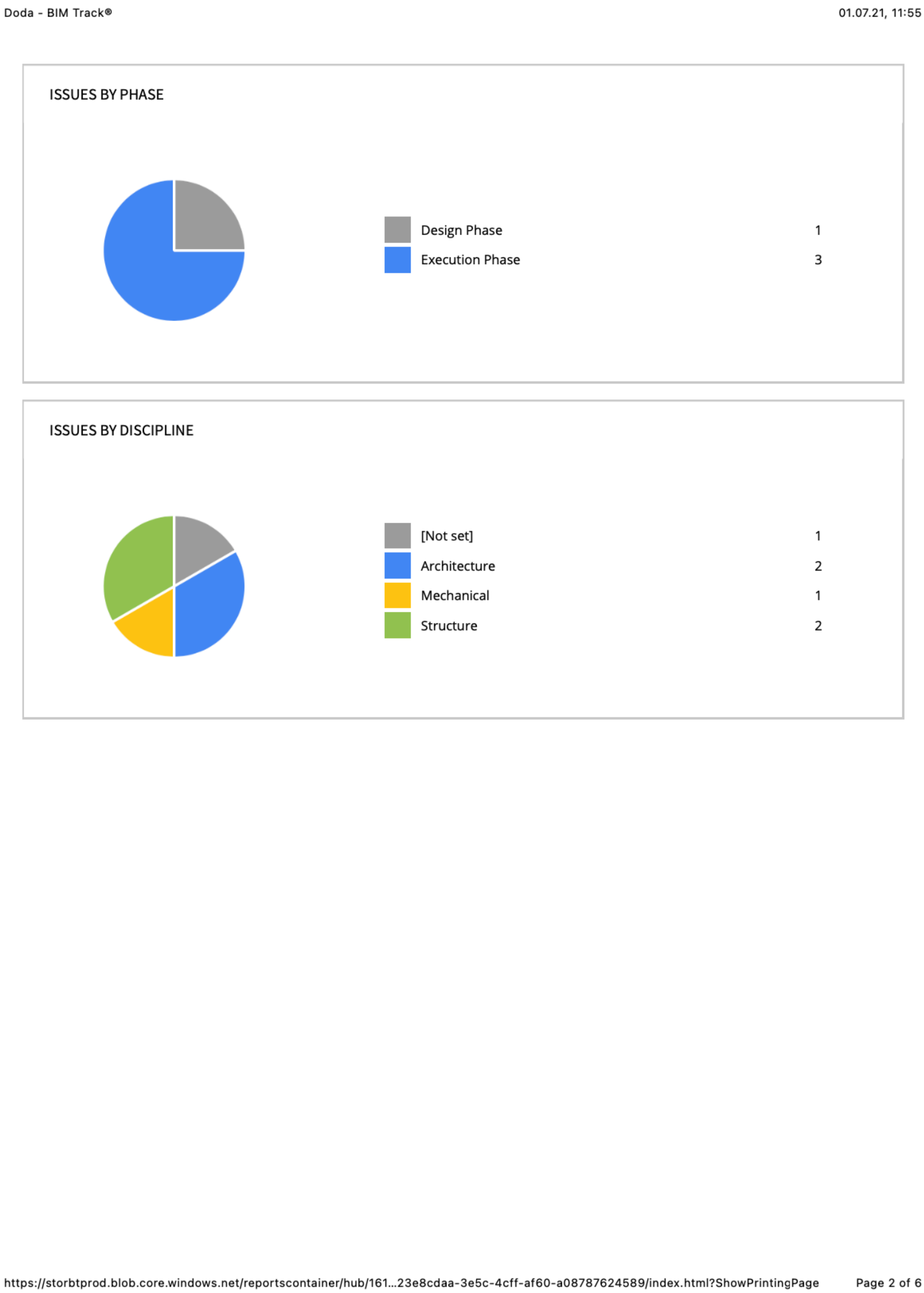
Title	All	Description	All
Assigned to	All	Zone	All
Type	Key Learnings	Phase	All
Priority	All	Discipline	All
Status	All	Group	All
Team involved	All	Author	All
Number	All	Visibility	All



https://storbtprod.blob.core.windows.net/reportscontainer/hub/161.../23e8cdaa-3e5c-4cff-af60-a08787624589/index.html?ShowPrintingPage Page 1 of 6

Figure 30: Final Issues Report, p. 1.[263]

[263] Own source, extracted from BIM Track web platform.


Doda - BIM Track®
01.07.21, 11:55

ISSUES BY PHASE

Design Phase	1
Execution Phase	3

ISSUES BY DISCIPLINE

[Not set]	1
Architecture	2
Mechanical	1
Structure	2

https://storbtprod.blob.core.windows.net/reportscontainer/hub/161...23e8cdaa-3e5c-4cff-af60-a08787624589/index.html?ShowPrintingPage
Page 2 of 6

Figure 31: Final Issues Report, p. 2.[264]

[264] Own source, extracted from BIM Track web platform.

Doda - BIM Track® 01.07.21, 11:55

eduardo_vendrusculo@hotmail.com

26. Hydraulic Project Unevenness

Description: The unevenness of the hydraulic project in comparison to the others, despite having created so many errors, also generated a greater use of time to be solved, which resulted in the delay of the project during the design phase.

Author	Eduardo Vendrusculo (eduardo_vendrusculo@hotmai...
Created	7/1/2021 9:30 AM
Last changed ...	Eduardo Vendrusculo (eduardo_vendrusculo@hotmai...
Last changed	7/1/2021 9:35 AM
Due date	7/8/2021 9:26 AM
Assigned to	
Type	Key Learnings
Priority	[Not set]
Status	Closed
Zone	
Phase	Design Phase
Discipline	
Group	
Team involved	
Notify	
Visibility	All users in project

https://storbtprod.blob.core.windows.net/reportscontainer/hub/161...23e8cdaa-3e5c-4cff-af60-a08787624589/index.html?ShowPrintingPage Page 3 of 6

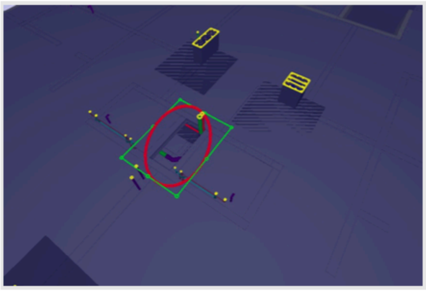
Figure 32: Final Issues Report, p. 3. [265]

[265] Own source, extracted from BIM Track web platform.

eduardo_vendrusculo@hotmail.com

23. Poorly Positioned Shaft

Description: The piping shafts in the middle of the slab provided great difficulties and required much more care during their execution due to the use of post-tensioned slabs. Re-evaluate locations in next project.



Author	Eduardo Vendrusculo (eduardo_vendrusculo@hotmai...
Created	6/10/2021 3:04 PM
Last changed ...	Eduardo Vendrusculo (eduardo_vendrusculo@hotmai...
Last changed	7/1/2021 9:42 AM
Due date	
Assigned to	Eduardo Vendrusculo (eduardo_vendrusculo@hotmai...
Type	Key Learnings
Priority	[Not set]
Status	Closed
Zone	
Phase	Execution Phase
Discipline	Mechanical, Structure
Group	
Team involved	
Notify	
Visibility	All users in project

COMMENTS

USER / DATE	COMMENTS
Designers R 7/1/2021 9:22 AM	The position for such a shaft is selected in accordance with the reduction of the excessive consumption of pipes in the work and thus is still considered the best option.
Eduardo Vendrusculo 7/1/2021 9:26 AM	The justification for such a position still has no value compared to the increase in on-site work for its realisation and should not be repeated in future projects.

Figure 33: Final Issues Report, p. 4. [266]

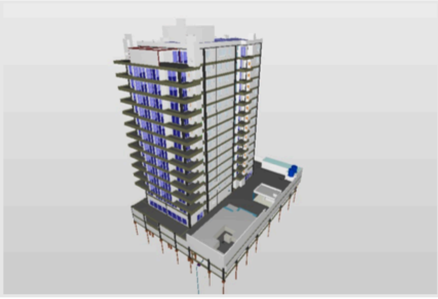
[266] Own source, extracted from BIM Track web platform.

Doda - BIM Track® 01.07.21, 11:55

eduardo_vendrusculo@hotmail.com

22. Poor Facilities Allocation

Description: When the facilities were designed inside the building, the climatic conditions were not well evaluated, especially with regard to the sun's rays in the bedrooms.
A redistribution of spaces within the apartment during the design phase would make perfect sense.



Author	Eduardo Vendrusculo (eduardo_vendrusculo@hotmai...
Created	6/10/2021 2:57 PM
Last changed ...	Eduardo Vendrusculo (eduardo_vendrusculo@hotmai...
Last changed	7/1/2021 9:13 AM
Due date	
Assigned to	Designers R (dodaven@gmail.com)
Type	Key Learnings
Priority	[Not set]
Status	Closed
Zone	
Phase	Execution Phase
Discipline	Architecture
Group	
Team involved	
Notify	
Visibility	All users in project

https://storbtprod.blob.core.windows.net/reportscontainer/hub/161...23e8cdaa-3e5c-4cff-af60-a08787624589/index.html?ShowPrintingPage Page 5 of 6

Figure 34: Final Issues Report, p. 5. [267]

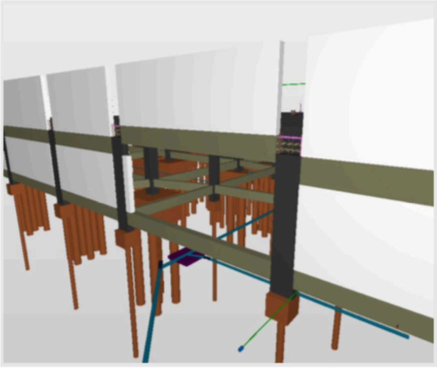
[267] Own source, extracted from BIM Track web platform.

Doda - BIM Track® 01.07.21, 11:55

eduardo_vendrusculo@hotmail.com

16. Beam Moved Downwards

Description: The beam was moved donwards 20 cms, thus increasing the span for car access.
The solution is to provide better access for large cars, commonly used due to the high agricultural activity in the region.



Author	Eduardo Vendrusculo (eduardo_vendrusculo@hotmai...
Created	6/10/2021 8:33 AM
Last changed ...	Eduardo Vendrusculo (eduardo_vendrusculo@hotmai...
Last changed	7/1/2021 9:14 AM
Due date	6/22/2021 9:00 PM
Assigned to	Eduardo Vendrusculo (eduardo_vendrusculo@hotmai...
Type	Key Learnings
Priority	[Not set]
Status	Closed
Zone	
Phase	Execution Phase
Discipline	Architecture, Structure
Group	
Team involved	
Notify	
Visibility	All users in project

https://storbtprod.blob.core.windows.net/reportscontainer/hub/161...23e8cdaa-3e5c-4cff-af60-a08787624589/index.html?ShowPrintingPage Page 6 of 6

Figure 35: Final Issues Report, p. 6.[268]

[268] Own source, extracted from BIM Track web platform.

List of Literature

Ackerman, M. S. & Malone, T. W. (1990). *Answer Garden: a tool for growing organizational memory.* New York, Association for Computing Machinery.

Alexander, R. (2018). *Bloomfire.* Available at: https://bloomfire.com/blog/implicit-tacit-explicit-knowledge/ [Accessed 13 August 2020].

Amin, M. B., Alauddin, M. & Azad, M. M. (2012). Business Transaction Processing System. *International Journal of Computer Information Systems,* 4(5), pp. 11-15.

Andreeva, T. & Ikhilchik, I. (2010). Applicability of the SECI Model of knowledge creation in Russian cultural context: Theoretical analysis. *Knowledge and Process Management: The journal of Corporate Transformation,* 18(1), pp. 56-66.

Anthony, R. N. (1965). *Planning and control systems; a framework for analysis.* Boston: Division of Research, Graduate School of Business Administration, Harvard University.

Archjoe. (2016). *Architecture background design Free Vector.* Available at: https://www.freepik.com/free-vector/architecture-background-design_1003820.htm#page=1&query=building%20sketch&position=4 [Accessed 16 July 2021].

Arif, M., Egbu, C., Alom, O. & Khalfan, M. M. (2008). Measuring knowledge retention: a case study of a construction consultancy in the UAE. *Engineering, Construction and Architectural Management,* 16(1), pp. 92-108.

Azimuth Interactive Inc. (2006). *Management Information Systems, Managing the Digital Firm.* Available at: https://paginas.fe.up.pt/~acbrito/laudon/ch2/chpt2-1main.htm [Accessed 13 February 2021].

Baldwin, M. (2018). *The BIM Collaboration Format (BCF).* Available at: https://bimconnect.org/en/software/the-bim-collaboration-format-bcf/ [Accessed 26 April 2021].

Barros, V. F. d. A., Ramos, I. & Perez, G. (2015). INFORMATION SYSTEMS AND ORGANIZATIONAL MEMORY: A LITERATURE REVIEW. *JISTEM - Journal of Information Systems and Technology Management,* 12(1), pp. 45-64.

Baskerville, R. & Dulipovici, A. (2006). The Theoretical Foundations of Knwledge Management. *Knowledge Management Research and Practice* , May, pp. 83 - 105.

Baskerville, R. L. & Myers, M. D. (2002). Information Systems as a Reference Discipline. *MIS Quarterly,* 26(1).

Beal, V. (n.d.). *Decision Support Systems - DSS.* Available at: https://www.webopedia.com/definitions/decision-support-system/ [Accessed 17 February 2021].

Bender, S. & Fish, A. (2000). The transfor of knowledge and retention of expertise: the continuing need for global assignments. *Journal of Knowledge Management,* 4(2), pp. 125-137.

BetterThesis. (n.d.). *Combining qualitative and quantitative methods.* Available at: https://betterthesis.dk/research-methods/lesson-1different-approaches-to-research/combining-qualitative-and-quantitative-methods [Accessed 17 May 2021].

BibLus. (n.d.). *BIM maturity Levels: from stage 0 to stage 3.* Available at: https://biblus.accasoftware.com/en/bim-maturity-levels-from-stage-0-to-stage-3/ [Accessed 7 April 2021].

BIM Track. (2018). *What is a BCF?.* Available at: https://bimtrack.co/blog/blog-posts/what-is-a-bcf [Accessed 26 April 2021].

BIM Track. (2020). *Your top 10 burning questions about BIM Track, answered.* Available at: https://bimtrack.co/blog/blog-posts/your-top-10-burning-questions-about-bim-track-answered#6 [Accessed 26 May 2021].

Bimspot. (2021). *Implementation Levels Of BIM In All Countries.* Available at: https://www.bimspot.io/blogs/implementation-levels-of-bim-in-all-countries/ [Accessed 7 April 2021].

Boddy, S., Rezgui, Y., Cooper, G. & Wetherill, M. (2007). *Computer integrated construction: A review and proposals for future direction.* Advances in Engineering Software, Volume 38 (10), pp. 677-687.

Bourgeois, D. T., Smith, J. L., Wang, S. & Moratati, J. (2019). *Information Systems for Business and Beyond.* Updated Edition ed. s.l.:Pressbooks.

Borrmann, A., König, M., Koch, C. & Beetz, J. (2018). Industry Foundation Classes – A standardized data model for the vendor-neutral exchange of digital building models. In: *Building Information Modelling, Technology Foundations and Industry Practice.* 1st Edition ed. Cham, Switzerland: The Springer, p. 3.

Botha, A., Kourie, D. & Snyman, R. (2008). *Coping with Continuous Change in the Business Environment, Knowledge Management and Knowledge Management Technology.* London: Chandice Publishing Ltd.

BuildingSMART. (n.d.). *BIM Collaboration Format (BCF).* Available at: https://technical.buildingsmart.org/standards/bcf/ [Accessed 26 April 2021].

BusinessDictionary. (n.d.). *Definition of Knowledge Management.* Available at: http://www.businessdictionary.com/definition/knowledge-management.html [Accessed 29 July 2020]

Çekin, E. & Seyis, S. (2020). *BIM Execution Plan based on BS EN ISO 19650-1 and BS EN ISO 19650-2 Standards.* Istanbul, s.n.

Cerovsek, T. & Katranuschkov, P. (2006). Active process-reuse model for collaboration. *Electronic Jounal of Information Technology in Construction,* Volume 11, pp. 467 - 488.

Cherry, K. (2020). *verywellmind.* Available at: https://www.verywellmind.com/what-is-memory-2795006 [Accessed 8 March 2021].

Cho, D., Russel, J. S. & Choi, J. (2013). Database Framework for Cost, Schedule, and Performance Data Integration. *Journal of Computing in Civil Engineering ,* 27(6), pp. 719-731.

Choo, C. W. (1995). *Information Management for the Intelligent Organization: Roles and Implications for the Information Professions.* Singapore, Information Today Inc., pp. 81-99, p. 81.

Choo, C. W. (n.d.). *Chun Wei Choo, Univesity of Toronto.* Available at: http://choo.ischool.utoronto.ca/IMfaq/ [Accessed 11 February 2021], n. p.

Creative Commons. (2012). *An Introduction to Business.* Available at: https://2012books.lardbucket.org/books/an-introduction-to-business-v1.0/s19-03-types-of-information-systems.html [Accessed 16 February 2021].

DATAROB. (2020). *Information vs data vs knowledge.* Available at: https://datarob.com/information-vs-data-vs-knowledge/ [Accessed 4 August 2020].

Demian, P. & Balatsoukas, P. (2012). Information Retrieval from Civil Engineering Repositories: Importance of Context and Granularity. *Journal of Computing in Civil Engineering,* 26(6), pp. 727-740.

Demian, P. & Fruchter, R. (2006). An ethnographic study of design knowledge reuse in architecture, engineering, and construction industry. *Reseach in Engineering Design,* 16(4), pp. 184-195.

Designing Buildings Wiki. (2020). (1). *BIM guidelines around the world.* Available at: https://www.designingbuildings.co.uk/wiki/BIM_guidelines_around_the_world [Accessed 12 April 2021].

Designing Buildings Wiki. (2020). (2). *Federated building information model.* Available at: https://www.designingbuildings.co.uk/wiki/Federated_building_information_model [Accessed 2 April 2021].

Designing Buildings Wiki. (2021). (1). *BIM maturity levels.* Available at: https://www.designingbuildings.co.uk/wiki/BIM_maturity_levels#Level_4_BIM [Accessed 8 April 2021].

Designing Buildings Wiki. (2021). (2). *Common data environment CDE.* [Online] Available at: https://www.designingbuildings.co.uk/wiki/Common_data_environment_CDE [Accessed 31 March 2021].

Designing Buildings Wiki. (2021). (3). *Knowledge management in construction.* Available at: https://www.designingbuildings.co.uk/wiki/Knowledge_management_in_construction [Accessed 19 April 2021].

Dubberly, H. & Evenson, S. (2011). *IX INTERACTIONS.* Available at: https://interactions.acm.org/archive/view/january-february-2011/design-as-learning-or-knowledge-creation-the-seci-model1 [Accessed 27 August 2020].

Eastman, C., Tiecholz, P., Sacks, R. & Liston, K. (2008). *BIM Handbook: A guide to Building Information Modeling for owners, managers, designers, engineers, and contractors.* 1st Edition ed. New Jersey: John Wiley.

Farnese, M. L., Barbieri, B., Chirumbolo, A. & Patriotta, G. (2019). *Managing Knowledge in Organizations: A Nonaka's SECI Model Operationalization.* Available at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.02730/full [Accessed 27 August 2020].

Fong, P. S. W. (2005). *Aspects of Learning and Knowledge in Construction Projects.* California , American Society of Civil Engineers.

Garcia, M. (2020). *Big Data: O que é, conceito e definição.* Available at: https://www.cetax.com.br/blog/big-data/
[Accessed 5 August 2020].

Girard, J. & Girard, J., 2015. Defining knowledge management: Toward an applied compendium. *Online Journal of Applied Knowledge Management,* 3(1), p. 14.

Godden, E. & Mansel-Thomas, L. (2016). *Digital Masterbuilders: Modernising Communication between Designers and Constructors.* London, UK, Ingleton Wood LLP.

Gregg Learning. (2020). *Decision Support Systems [Video]. Youtube.* Available at: https://www.youtube.com/watch?v=114DipNd1n8 [Accessed 17 February 2021].

Hajric, E. (2018). *Knowledge Management: System and Practices.* Jacksonsville: s.n.

Hatch, J. (2010). *Defining Organizational Knowledge: Turning individual knowledge into organizational intellectual capital.* Available at: http://knol.google.com/k/defining-organizational-knowledge [Accessed 10 March 2021], p. 278.

Hengsberger, A. (2019). *What is Building Information Modeling (BIM) and what changes does it entail?.* Available at: https://www.lead-innovation.com/english-blog/building-information-modeling [Accessed 9 April 2021].

Hertzum, M. & Pejtersen, A. M. (2000). Information-seeking practices of engineers: Searching for documents as well as for people. *Information Processing and Management,* 36(5), pp. 761-777.

Hicks, B., Dong, A., Palmer, R. & Mcalpine, H. (2008). Organizing and managing personal electronic files. *ACM Transactions on Information Systems,* 26(4), pp. 1-40.

Horvath, J. (2000). Working with Tacit Knowledge. In: J. W. Cortada & J. A. Woods, eds. *The Knowledge Management Yearbook.* s.l.:Butterworth-Heninemann, pp. 34-51.

Howard, R., Björk, B. C. (2008). *Building information modelling – Experts' views on standardization and industry deployment.* Advances Engineering Informatics, Volume 22 (2), pp. 271-180.

Joshi, K. (n.d.). *Transaction Processing and Management Reporting Systems.* Available at: http://www.umsl.edu/~joshik/msis480/chapt09.htm [Accessed 15 February 2021].

Kaufmann, E., Favretto, J., Filippim, E. S. & Cohen, E. D. (2019). Relationship Between The Organizational Memory and Innovativity: The Case of Software Development Companies in The Southern Region of Brazil. *JISTEM - Journal of Information Systems and Technology Management,* Volume 16.

KMT. (2018). *Knowledge Management Tools.* Available at: http://www.knowledge-management-tools.net [Accessed 3 August 2020].

Kuo, V. (2019). *Latent Semantic Analysis for Knowledge Management in Construction.* Helsinki: Aalto University, p. 34.

Leite, F. (2020). *BIM for Design Coordination: A virtual Design and Construction Guide for Designers, General Contractors, and MEP Subcontractors.* New Jersey: John Wiley & Sons.

Li, W. & Leite, F. (2014). *Comparison of Experienced and Novice BIM Coordinators in Performing Mechanical, Electrical, and Plumbing (MEP) Coordination Tasks,* Georgia: American Society of Civil Engineers Construction Research Congress 2014.

Lorek, S. (2021). *What is BIM (Building Information Modeling).* Available at: https://constructible.trimble.com/construction-industry/what-is-bim-building-information-modeling [Accessed 29 April 2021].

Magalhães, I. L. (2015). *Tacit & Explicit Knowledge.* Available at: https://www.linkedin.com/pulse/tacit-explicit-knowledge-ivan-luizio-magalhães/ [Accessed 19 August 2020].

Manhanta, A. (2018). *Data, Information, Knowledge and Processing.* Available at: https://pt.slideshare.net/mahantaanjan/data-information-knowledge-and-processing [Accessed 5 August 2020].

Martínez-Rojas, M., Marín, N. & Vila, M. A. (2015). An Approach for the Automatic Classification of Work Descriptions in Construction Projects. *Computer-Aided Civil and Infrastructure Engineering ,* 30(12), pp. 919-934.

McDonald, A. (2011). *Pinterest.* Available at: https://www.pinterest.com/pin/504895808208429567/ [Accessed 13 February 2021].

McPartland, R. (2016). *What is the Common Data Environment (CDE)?.* Available at: https://www.thenbs.com/knowledge/what-is-the-common-data-environment-cde [Accessed 31 March 2021].

McPartland, R. (2017). *What is a federated Building Information Model?.* Available at: https://www.thenbs.com/knowledge/what-is-a-federated-building-information-model [Accessed 31 March 2021].

Merriam-Webster. (2020). *Knowledge.* Available at: https://www.merriam-webster.com/dictionary/knowledge [Accessed 29 July 2020].

Natrop, M. (2020). *BIM, the game-changer.* Available at: https://www.e-zigurat.com/blog/en/bim-methodology-changed-rules-game/ [Accessed 2021 July 22].

NBS. (2019). *National BIM Report 2019,* New Castle : NBS Enterprises Ltd.

Nicoleta, P. (2019). *The need for BIM Standards in digital construction.* Available at: https://www.breakwithanarchitect.com/post/the-need-for-bim-standards-in-digital-construction [Accessed 12 April 2021].

Nonaka, I. & Konno, N. (1998). The Concept of 'Ba': Building a Foundation for Knowledge Creation. *California Review Management*, 1 April, pp. 40-54.

Omotayo, F. O. (2015). *Knowledge Management as an important tool in Organisational Management: A Review of Literature.* Available at: https://digitalcommons.unl.edu/libphilprac/1238/?utm_source=digitalcommons.unl.edu%2Flibphilprac%2F1238&utm_medium=PDF&utm_campaign=PDFCoverPages [Accessed 25 August 2020].

O'Dell, C. & Grayson, C. J., 1998. *If Only We Knew What We Know; The Transfer of Internal Knowledge and Best Practice.* New York: The Free Press, p. 8.

Perez, G. & Ramos, I. (2013). UNDERSTANDING ORGANIZATIONAL MEMORY FROM THE INTEGRATED MANAGEMENT SYSTEMS (ERP). *Journal of Information Systems and Technology Management,* 10(3), pp. 541-560.

Poljanšek, M. (2017). *Building Information Modelling (BIM) standardization,* Ispra, Italy: Joint Research Centre (JRC), the European Commission's science and knowledge service.

Prusak, L. (2001). Where did knowledge management come from? *Journal IBM Syst. J.* 40, pp. 1002-1007.

Rainer, R. K. J. et al. (2020). *Introduction to Information Systems.* Firth Canadian Edition ed. Toronto: Wiley.

Rhem, A. J. (2017). *Knowledge Management in Practice.* First Edition. Auerbach Publications.

Rezgui, Y., Hopfe, C. & Vorakulpitat, C. (2010). Generations of knowledge management in the architecture, engineering and construction industry: An evolutionary perspective. *Advanced Engineering Informatics,* 24(2), pp. 219-228.

Roehrs, R. (2021). *Residencial Âmbar.* Ijuí, Brazil: Engeter Engenharia.

Shen, Z. (2010). *Quantitative evaluation of the BIM-assisted construction detailed cost estimates.* Journal of Information Technology in Construction (ITcon), Volume 15, pp. 234-257.

Solibri Inc. (2019). *What Is Solibri BCF Connector?.* Available at: https://solibri-community.force.com/know2/s/article/UUID-6bc30391-ef7d-8f11-5b9a-a1e9942fa7f5 [Accessed 24 May 2021].

Solibri Inc. (2021). (1) *Rulesets Description,* Helsinki, Finland: Solibri Inc..

Solibri Inc. (2021). (2) *Solibri Office.* Available at: https://www.solibri.com/solibri-office?utm_source=adwords&utm_campaign=SEM+-+Solibri+Offering&utm_medium=ppc&utm_term=solibri%20office&hsa_ver=3&hsa_grp=112672018752&hsa_acc=5457118427&hsa_ad=475827851975&hsa_src=g&hsa_tgt=kwd-811449858126&hsa_kw=solibri% [Accessed 18 July 2021].

Sollien, J. A. (2020). *BCF REST API.* Available at: https://github.com/buildingSMART/BCF-API/blob/release_2_1/README.md#1-introduction [Accessed 24 May 2021].

Stein, E. W. & Zwass, V. (1995). Actualizing Organizational Memory with Information Systems. *Information Systems Research,* 6(2), pp. 85-117.

Sutner, S. (2020). *Business Intelligence Dashboard.* [Online] Available at: https://searchbusinessanalytics.techtarget.com/definition/business-intelligence-dashboard [Accessed 17 February 2021].

Techopedia. (2012). *Executive Support System (ESS).* [Online] Available at: https://www.techopedia.com/definition/543/executive-support-system-ess [Accessed 17 February 2021].

Terra, J. C. & Angeloni, T. (2003). *Understanding the difference between information management and knowledge management.* Available at: http://www.providersedge.com/docs/km_articles/understanding_the_difference_between_im_and_km.pdf [Accessed 4 March 2021].

Tserng, H. P. & Yu-Cheng, L. (2004). Developing an activity-based knowledge management system for contractors. *Automation in Construction ,* November, 13(6), pp. 781-802.

Tsoukas, H. & Vladimirou, E. (2001). What is organizational knowledge?. *Journal of Management Studies ,* Issue 38, pp. 973-993.

Virkus, S. (2014). *Tallinna Ülikool, Key Concepts in Information and Knowledge Management.* Available at: https://www.tlu.ee/~sirvir/Information%20and%20Knowledge%20Management/Key_Concepts_of_IKM/index.html [Accessed 30 July 2020].

Walsh, J. P. & Ungson, G. R. (1991). Organizational Memory. *Academy of Management Review,* 16(1), pp. 57-91.

Wilson, T. (2002). *The nonsense of 'knowledge management'.* Available at: http://informationr.net/ir/8-1/paper144.html [Accessed 11 February 2021].

Wyatt, J. C. (2001). Management of explicit and tacit knowledge. *JOURNAL OF THE ROYAL SOCIETY OF MEDICINE,* Volume 94, pp. 6-9.

Zhang, X. (2013). The Evolution of Management Information Systems: a literature review. *Journal of Integrated Design & Process Science,* 17(2), pp. 59-88.