The European Master in Building Information Modelling is a joint initiative of:

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From BIM to Asset Management - data-driven guidelines for Operations & Maintenance

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BIM A+

UMinho | 2022

Universidade do Minho
Escola de Engenharia

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Co-funded by the Erasmus+ Programme of the European Union

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Master Dissertation
European Master in Building Information Modelling

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Co-funded by the
Erasmus+ Programme
of the European Union

October 2022

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ACKNOWLEDGEMENTS

First, I am profoundly grateful for the Erasmus Mundus Joint Master Degree (EMJMD) scholarship attribution, provided by the European Union, which enabled my participation at BIM A+ European Master in Building Information Modelling.

To my supervisors, Professor Bruno Figueiredo and Professor Hélder Sousa, for their constant availability, encouragement, and guidance through this work.

To Sébastien Roux and Filipe Lima, tutors in company from LIMSEN Consulting BIM & VDC Services, for agreeing to collaborate on this project with me and giving me multiple opportunities for in-depth, fruitful learning. My gratitude goes out to the entire team for welcoming me with such warmth and for all the talks and ideas that demonstrated how technology and innovation are used in everyday work.

To all the Master's associated partners, particularly Dalux, who was always accessible to provide software and answer any issues that came up throughout the course of the work.

To my family, for their incessant love and support, for always encouraging me to pursue my goals and for all they gave up so I could accomplish my hopes. Without them, this effort would not be feasible.

To my lifetime friends, for accompanying me wherever I go.

And finally, to my colleagues in the BIMA+, who have grown to be friends through all the long nights of work, experiences, and moments of sharing.

STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

Rita Nogueira Granjo dos Santos

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Rita Nogueira Granjo dos Santos

RESUMO

Cada vez mais, o BIM é considerado como um elemento-chave no projeto, fabricação e gestão de informação digital na indústria AECO/O. A visualização tridimensional, quando combinada com a criação de uma base de dados permite a compreensão abrangente dos ativos, possibilitando o desenvolvimento contínuo e iniciando um ciclo de aprendizagem do ambiente construído.

De todas as etapas de trabalho de um edifício, a fase de operação e manutenção, muitas vezes conhecida como fase “em uso”, é sinalizada como o maior custo no seu ciclo de vida. A recolha de dados relevantes para a atividade de Gestão de Instalações pode absorver mais de 80% do tempo disponível das equipas.

A integração BIM pode auxiliar a indústria de AECO/O, atuando como um banco de dados dinâmico que evolui desde as fases iniciais de projeto, onde o BIM se desenvolve como uma solução completa para Gestão de Instalações, capaz de impulsionar fluxos de trabalho usando tecnologias recentes combinadas com processos orientados por dados.

Cercada por uma multitude de fornecedores de *software*, a indústria vem reivindicando o desafio de determinar quais ferramentas a utilizar para transmitir efetivamente as informações para o Gestão de Instalações. Considerando os potenciais procedimentos que possibilitam as práticas de transmissão BIM-FM, pode-se encontrar um procedimento estruturado de entrega de dados, oferecido pelo protocolo de troca aberta COBie. O COBie destaca-se como uma ferramenta independente de fornecedor, capaz de fazer a transmissão de dados entre o Projeto e as etapas subsequentes, pois pode ser exportado de uma ferramenta de autoria BIM e utilizado em soluções de Gestão de Ativos Digitais. Além disso, permite aos proprietários e operadores implementar diferentes sistemas de manutenção, ao mesmo tempo em que fornece dados, verificáveis, confiáveis e precisos.

A ausência de uma estrutura com variáveis de informação organizada constitui um hiato na consciencialização da utilização de informação gerada em BIM para integração em Gestão de Instalações, o resultado esperado desta dissertação é o desenvolvimento de um guia de utilização do COBie, uma ferramenta abrangente capaz de auxiliar a produção de entregáveis COBie válidos.

O estudo de caso foi usado para implementar a ferramenta desenvolvida, em colaboração com um parceiro do mestrado, a LIMSEN Consulting. O desenvolvimento, a avaliação e a validação da ferramenta consistem nas três fases do procedimento que visam fornecer informação concisa sobre requisitos, responsabilidades e contextos para a entrega de dados. Finalmente, o trabalho apresentado visa fortalecer a prontidão da indústria para a transição de práticas orientadas a documentos para processos automatizados baseados em modelos e orientados por dados.

BIM, COBie, Operações & Manutenção, Gémeo Digital, Troca de Informação.

ABSTRACT

BIM is increasingly considered as a key driver in the design, manufacturing, and management of digital information in the AECO/O industry. The tridimensional visualization combined with the data collection allows for a comprehensive understanding of assets, enabling continuous development, and launching a learning cycle for the built environment.

Out of all work stages of a building, the operations and maintenance phase, often known as the “in use” phase, is flagged as the major cost in its lifecycle. Hunting relevant data for Facility Management (FM) may absorb over than 80% of the teams available time.

BIM integration can assist the FM industry, by acting as a dynamic data pool evolving from preliminary stages of Design, BIM develops into a complete solution for FM, capable of boosting workflows by using recent technologies combined with data-driven processes.

Surrounded by a swarm of software providers, the industry has been claiming the challenge of determining which tools to effectively transmit information to the FM stage. Out of the potential procedures that enable BIM-FM linking practices, a structured data delivery procedure can be found, offered by the open exchange protocol COBie. COBie stands out as a vendor-neutral tool, capable of data bridging between Design and subsequent stages, as it can be exported from a BIM authoring tool and loaded into Digital Asset Management solutions. Additionally, it liberates owners and operators to deploy different maintenance systems, while providing reliable and accurate data.

Given that the lack of a clear framework continues to hinder BIM data awareness for integration inside facilities management, the expected outcome of this dissertation is the development of a comprehensive COBie guide, a tool cable to assist teams in producing valid COBie deliverables.

A case study was used to implement the developed tool, in collaboration with a business partner, LIMSEN Consulting. The tool development, evaluation, and validation consist of the three major phases of the procedure intended to provide clear information requirements, responsibilities, and data drops. Finally, the presented work aims to strengthen the industry's readiness to transition from document-oriented practices into model-based, data-driven automated processes.

BIM, COBie, Digital Twin, Information Exchange, Operations & Maintenance

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1. INTRODUCTION

BIM increased the digitization of current procedures within the AECO/O (Architecture, Engineering, Construction, Operation & Owners) sector. It constitutes a procedure driven by technology that offers several opportunities to improve decisions during the Design, Construction, Handover, and Use of built assets. The necessity for asset management to be digitalized is expanding as the digital era progresses. (Shahzad *et al.*, 2022).

Information about an item and its attributes may be transferred and stored using BIM throughout the object's lifespan, however, the major problem consists in the divergence between as-designed, as-built, and as-is facilities. Significant research has been conducted regarding data management in Design and Construction phases, leaving information management in following stages facing the absence of a structured framework. A seamless information flow between all the involved parties is still challenged, due to the narrow definition of concrete data requirements (Wijekoon *et al.*, 2017).

According to recent studies conducted by Halmetoja and Lepkova, (2022), developing solutions that make advantage of the transfer of semantic data from BIM for usage in FM software should prioritized. The specification and formalization of the information required for creating, maintaining, and using an asset management model stands as a crucial element in allowing BIM's practical implementation in the Operations & Maintenance (O&M) inside FM. From the available options for integrating information from early stages into downstream phases, COBie was noticed as a pertinent tool to be explored, since it is open-source and vendor neutral, it has the potential to be a versatile, flexible procedure to make use of.

Overall, this research aims to clarify and structure the information transmission from the Design stages to the Handover, by first understanding the information management lifecycle and hereafter defining, assessing, and validating the required information for the O&M (also known as "In Use") phase. The expected outcome is to assist in the creation of comprehensive guide to COBie (Construction Operations Building Information Exchange), deploying a tool capable perform data transfer from the Design to the subsequent stages, ensuring that the inserted data provides efficient use during the whole building lifecycle.

Therefore, the primary goal of this dissertation is to develop a framework for COBie, centred on existing standards and publications, clarifying which information should be delivered, the correspondent timeframes and the involved parties, and identifying the roles and responsibilities of the involved actors.

The outcome will be a practical, engaging tool that allows the users to understand this resource, empowering its practice by the teams and guaranteeing a successful integration of BIM outputs into the FM systems, ensuring that information developed in early stages can be used effectively throughout the entire Building Lifecycle Management.

This dissertation comprises a total of six chapters, summarised in Figure 1. The first chapter corresponds to the introduction and starts to present the problem and the theme with hypotheses, the purpose, and objectives of the research, followed by a brief description of the general organization of the work by chapter, the research methods used, and the evaluation of the studies carried out to the moment. The second chapter presents the context of BIM in the 4.0 era, as well as current visions about BIM use within O&M. The third chapter focuses on asset management, starting with a brief state of the art concerning FM and asset-related standards and specifications and followed by an overall non-extensive panorama of available Software as a Service (SaaS) for FM. The fourth chapter studies the feasible linking procedures from BIM to FM and identifies information requirements for the O&M phase, structuring a proposal considering the use of COBie. Chapter five refers to the creation, assessment, and validation tool in a case study, initially from the integration with Planerly Platform, followed by the application inside the authoring software and finally by showing the integration with a digital asset management tool. The sixth chapter concludes the study by identifying the aspects to be improved, contributing suggestions for a better performance of developed tool, and pointing out suggestions for future research.

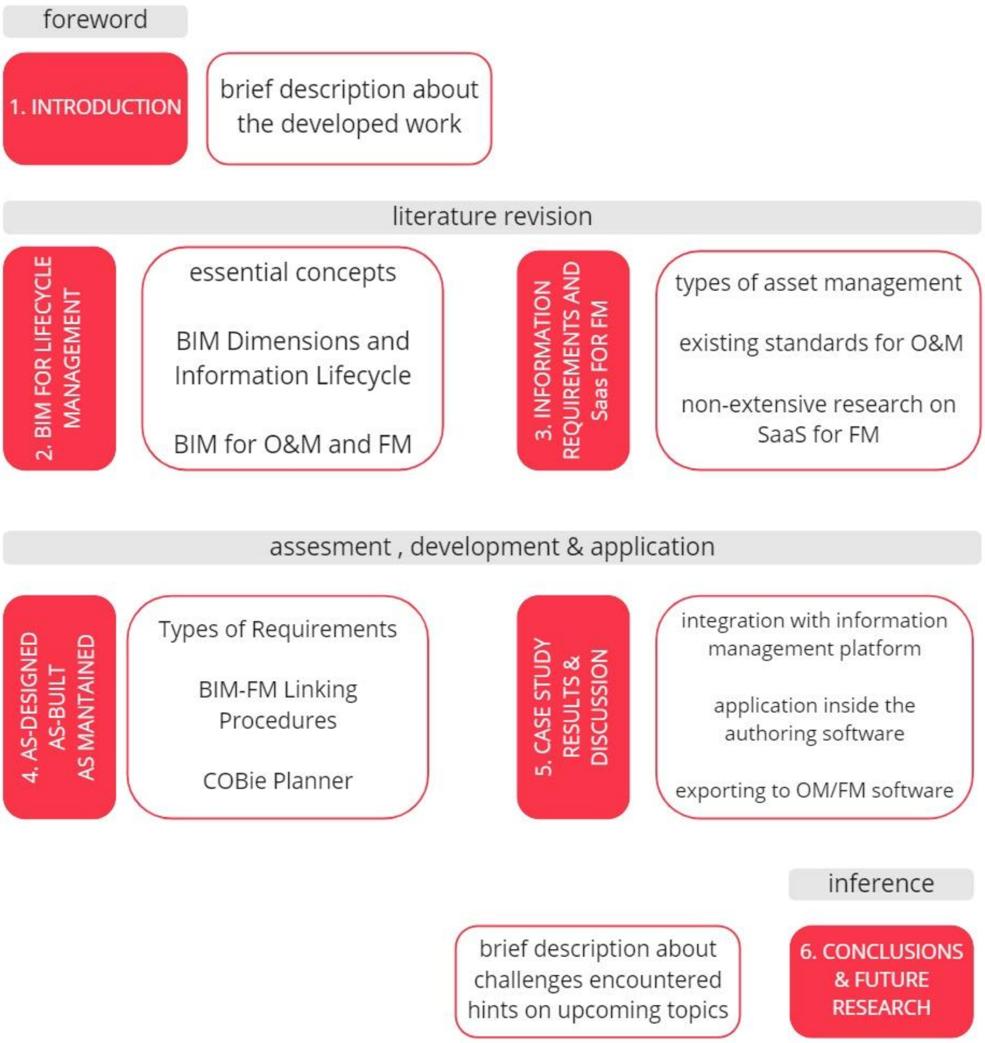

Figure 1 – Dissertation outline

The present work appealed to two main methods of research, one regarding the literature review, and the other to the development of the proposed tool and its application to the case study. The preceding processes will then be thoroughly detailed, linking the work's organization to the methodologies and objectives described in Figure 5.

Regarding to the first stage, the literature review was completed with the assistance of the VOS Viewer, (Jan van Eck and Waltman, 2022) which allows the construction and visualization of bibliometric networks. These networks can include multiple sources that can be built based on different criteria. The initial step involved defining the keywords., which in this study were five – BIM, Operations Maintenance, Facility Management, Information Exchange, COBie, & Digital Twins. Electronic databases were used to search for articles, books, book chapters, and conference papers. The applied filters were the idiom of the source being English and a year range from 2012-2022 were considered, being exclusion criteria elements unrelated to the scope of BIM-FM, beyond the defined period, without an available abstract or written in a different idiom. Figure 2 summarizes the described process.

Figure 2 – Literature Review Schema

The selected elements were exported into the VOS Viewer, and a co-occurrence map based on text data was created, with the title and abstract field included in a full-counting term method. A minimum number of 5 occurrences was set and terms with a level of relevance under 0.5 were deleted. Electronic databases (ScienceDirect, Lens, ResearchGate) were used for the first stage, while a reference manager was used for the second stage.

Towards a better understanding of the overall literature, two networks were generated. The first one relates to the initial research, which comprised 1271elements, such as journals, books, reports, and conference proceedings, from an online database. The generated network can be seen in Figure 3. After the screening, in the second step, a smaller number of 78 sources was selected, considering the criteria described earlier in this section. In both graphs, it is possible to identify the clusters, separated by colour. The size of the circles/words relates to the relevance of the word within the research environment.

In the primary network – Figure 3– which is broader, Information Modeling (or Modelling) and Facility Management, give the motto to this research, followed by Automation, Issue, and Volume. The first three words are related to the theme as they stand out from the overall and are connected amongst each other. The second group can be logically integrated with the previous, as Automation is, without doubt, an indissociable part of the digital era, trying to solve Issues faster, effectively, and wisely. The volume appears connected to asset/facilities management, in the same cluster as information modelling, and can be related to several concepts, such as the generated data volume or the queries volume.

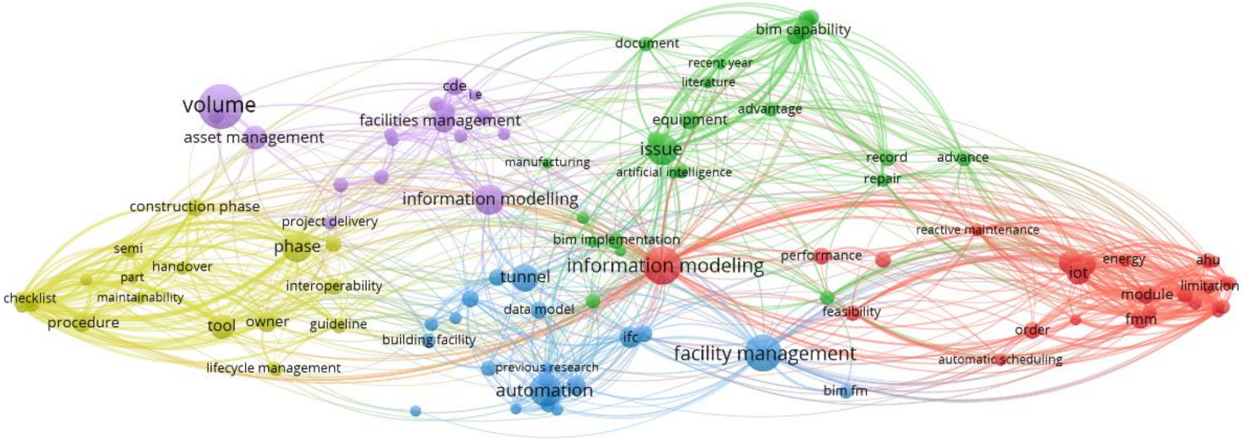

Figure 3 – Primary Bibliographic network

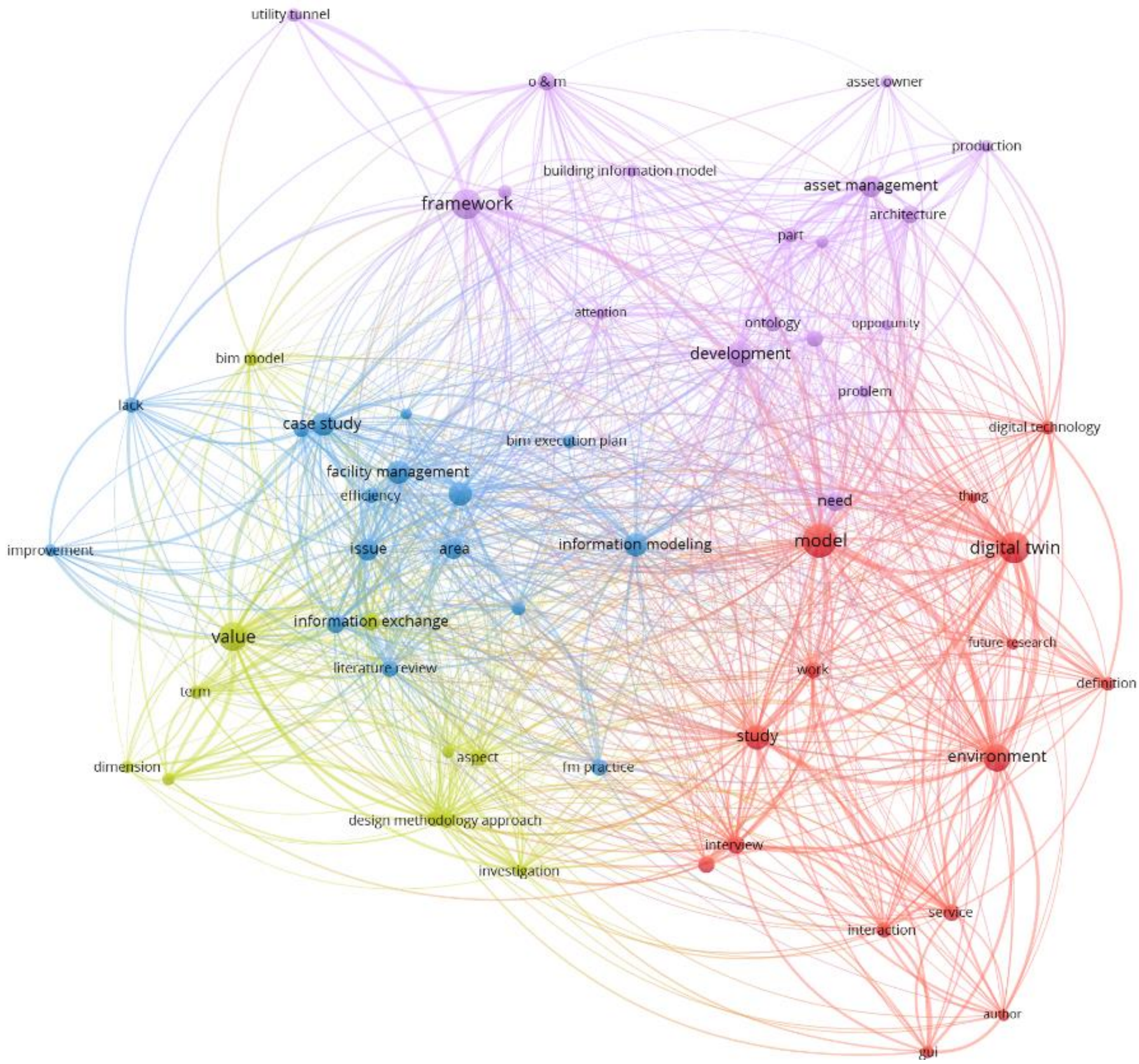

Figure 4 – Filtered Bibliographic network

In the second network – Figure 4. The clusters become more dispersed but at the same time more word-specific in each one, like value–digital methodology approach–investigation; information exchange–facility management–case study; framework–development–asset management; digital twin–

environment–model. This result can be interpreted as small-scale areas of investigation within the general theme and associated with the previously proposed work structure. The dissertation's anatomy was drafted considering the obtained clusters. Chapters 2 and 3 of this dissertation can be related to yellow and blue clusters, respectively. Chapter 2 creates the background of the proposed problem, by introducing a broader scope and revisiting fundamental BIM-related concepts, while chapter 3 goes more specifically into FM notions and tools. Chapters 4 and 5 connect to the purple one and consist of the second phase of this work, by focusing on the assessment of the conditions needed for the case study construction, by defining the information requirements, based on previous studies' findings and professionals' insights. Chapter 6 connects to the red cluster, launching future research perspectives and identifying the limitations on the current study - Figure 5.

The second main stage of the dissertation reflects the work developed in collaboration with the partner company LIMSEN, which is a BIM Consultancy company, with experience in managing a wide range of project types, comprising different scales and areas of operation. The majority of LIMSEN's workflow is focused on Information Management regarding BIM processes, from Design to Handover stages. The proposed methodology to this stage combined the collection internal document samples with external recognized examples and procedures. After the data gathering, a synthesis of the information found in both sources was completed, followed by a critical assessment of its applicability. These two steps combined allowed to create a customized tool suitable to fulfil the company's needs.

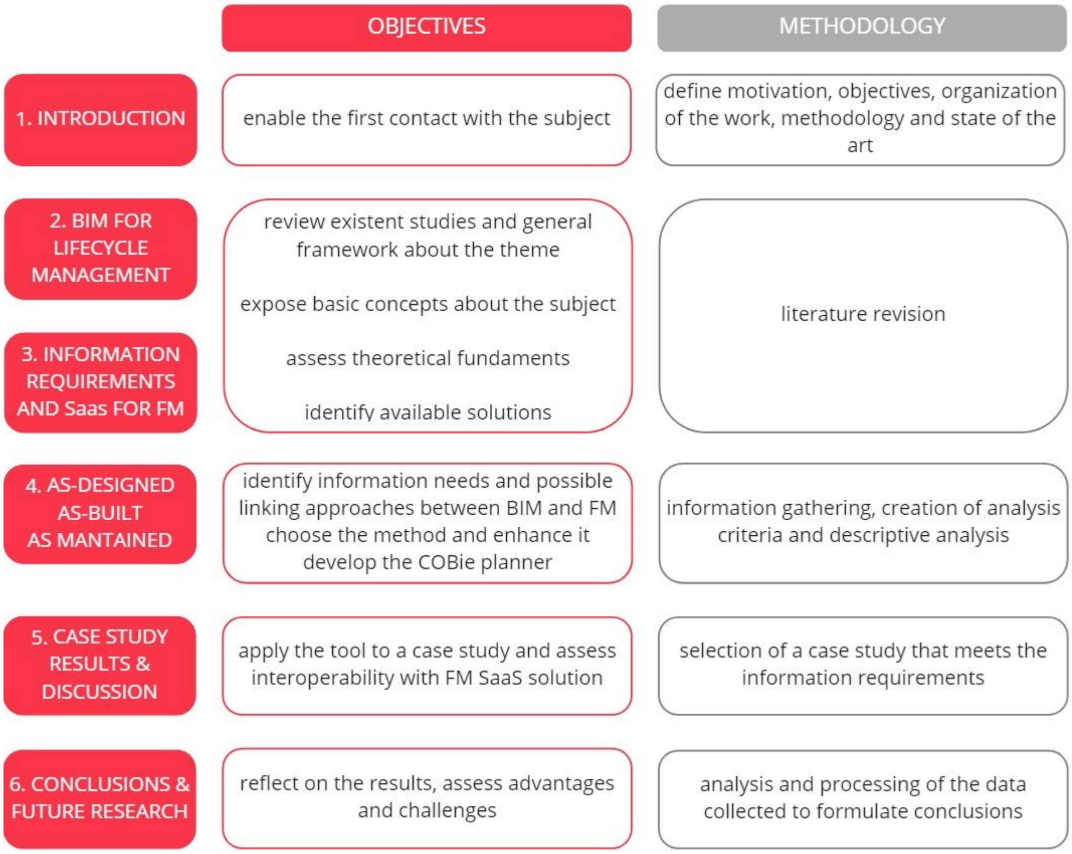

Figure 5 – Proposed Objectives & Methodology

BIM is identified as the potential backbone of FM systems, since it consists of data–driven processes that when combined with recent technologies, can boost productivity workflows. (Naghshbandi, 2016) The progression of information transmission methods from manual to automated, as well as the increase of accuracy and access to shared data, are all points of agreement and added value that BIM offers, stated by multiple authors. (Edirisinghe *et al.*, 2017; Florez and Afsari, 2018; Kassem *et al.*, 2015; Patacas *et al.*, 2020)). Being a dynamic *data pool,* as it is in constant evolution since the early stages of Design, BIM becomes a comprehensive solution for FM.

However, if several have already highlighted the benefits of BIM in the FM phase, why effective implementation is yet a challenge? A wide range of BIM-FM issues was pointed out during the last decade by several authors and summarized by (Dixit *et al.*, 2019) from technical (interoperability) to business (Return on Investment), legal (model liability, ownership rights) and human (training, accountability) barriers to BIM-FM networking. (Pärn *et al.*, 2016) go further into this question, saying that the advantages of BIM for O&M are still questionable because of the non-existent supply/demand chain, meaning the lack of client procurement. Overall, a common concern consists in how to perform effective transmission of information to the FM stage.

Research conducted by (Dixit *et al.*, 2019; Farghaly *et al.*, 2016; Lavy and Jawadekar, 2014) note the use of accessible and conventional communication protocols to standardize the information exchange in all tiers of contact resulted from efforts to give more effective and efficient solutions to the interoperability concerns. Without the additional step of data extraction, information shaped by COBie may be utilized for operations and maintenance on its own.

Strong information management procedures are essential for the upkeep and function of built assets (Becerik-Gerber *et al.*, 2012a; Wijekoon *et al.*, 2017), however, finding a consistent method to determine the information requirements for FM usage persists demanding. (Dixit *et al.*, 2019; Matarneh *et al.*, 2018). The general idea amongst the literature is that the investment in the quality and granularity of the information is quite substantial in the Design phase, decreasing in the subsequent phases of Construction and Handover/ FM. Moreover, recent studies show that the number of standards, guidelines, and norms related to the transmission of the information at the Design stage far exceeds those related to FM or asset management. Many of those that exist do not even refer to BIM processes (Lu *et al.*, 2022).

This situation is rather paradoxical given that O&M is listed as the principal expenditure during the building's lifetime. Building's life cycle expenditures are inflated by the O&M stage, accounting for some 70 to 85% of its total cost (Kelly *et al.*, 2013; Matarneh *et al.*, 2018).

Facing the previous statements, it urges to close the information gap in from BIM to FM, by providing useful guidance in on how to use the available resources and how to deliver effective information capable of creating value through all the building lifecycle. The readiness of the industry to face upcoming challenges as Digital Twins, will depend on moving from document-oriented practices into model-based, data-driven automated procedures.

2. BIM FOR LIFECYCLE MANAGEMENT

2.1. Industry 4.0, Construction, and Digital Transformation

Working and living patterns are being changed by the rise of new technologies and approaches. Major milestones in the history of industry are getting closer through time, a phenomenon that is significantly enhanced by digital evolution and transformation –Figure 6.

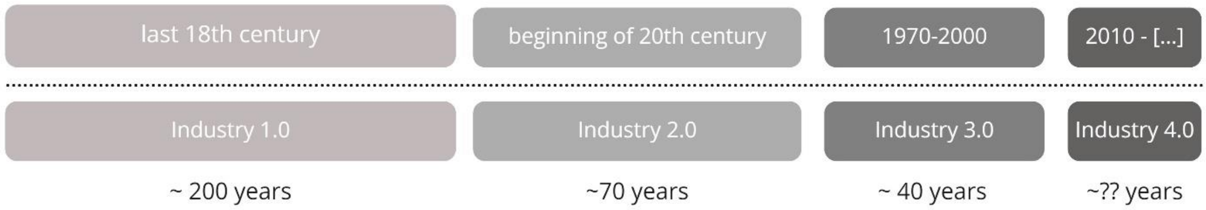

Figure 6 – Evolution of the industry stages based on Sawhney *et al.*,(2020)

The Fourth Industrial Revolution, often identified as Industry 4.0, is a rather recent concept, consisting of an ongoing transition, with various levels of adoption, depending on the industries, and that is why it is so challenging to establish a common definition for it (Bolpagni *et al.*, 2022). Its key components can be identified in Figure 7 as Internet of Things (IoT), Cyber-physical Systems, Cyber Production Systems, and Internet of data and Services. (Sawhney *et al.*, 2020).

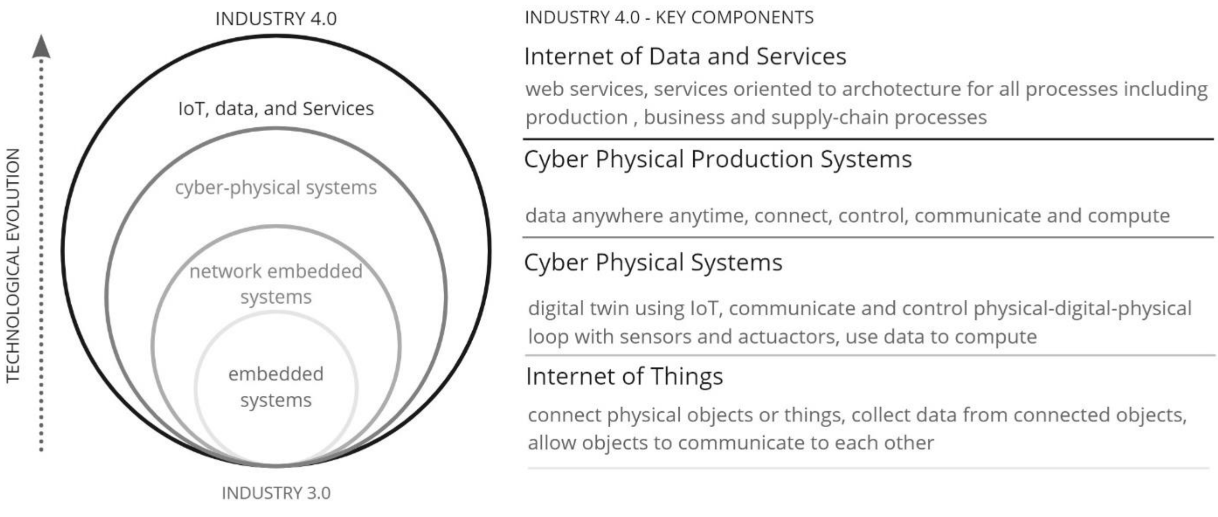

Figure 7 – Industry 4.0 technological evolution and key components based on Sawhney *et al.*, (2020)

Construction 4.0 is the convergence of a digital ecosystem with the previous cyber-physical system as it is represented by Figure 8. It is enabled by digital developments, such as 3D printing and automated systems for manufacturing and assembly, combined with digital technologies, such as BIM, AR/VR (Augmented Reality/ Virtual Reality) , IoT (Internet of Things), AI (Artificial Intelligence), big data, and analytics, among others. Overall, it is a set of technologies, concepts, and soft skills, combined to re-shape and enhance the process of designing and constructing the built environment.

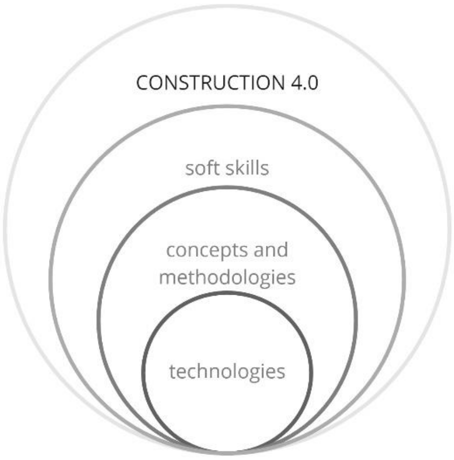

Figure 8 –Construction 4.0 main clusters – based on Bolpagni *et al.*, (2022)

Despite the Construction Industry being the second less digitized and tech innovative trade and a later adopter of new technologies which rely on traditional processes and deliverables (Rogers and Kirwan, 2019), all the previous industrial revolutions until the present had a significant impact on it. As usual in new concepts, it is confronting multiple challenges, mostly related to the adoption of new processes and the embracement of new technologies, summarized in the schema in Figure 9. Regarding positive outcomes, new job opportunities are being created, which also brings the need for new technical knowledge and skills. Considering the previous statements, the construction industry can now benefit from the fourth industrial revolution, taking advantage of the digital data available and the interconnection between physical and digital assets.

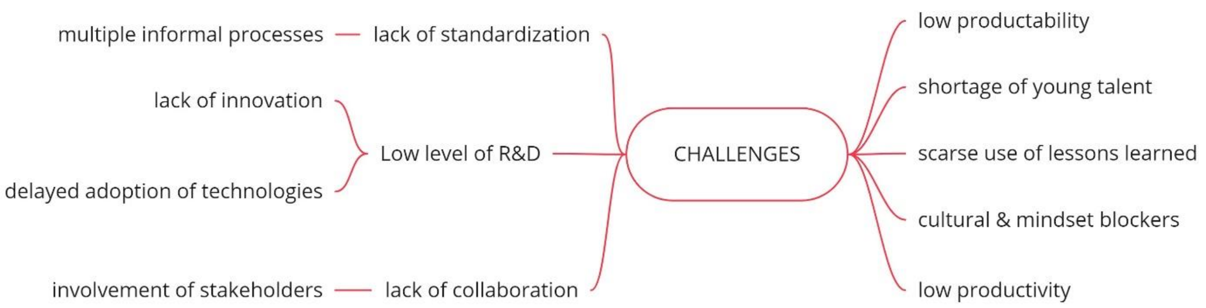

Figure 9 – Construction 4.0 current challenges – based on Bolpagni *et al.*, (2022) and Sawhney *et al.*,(2020)

How information is managed, transferred, and modified between the project stakeholders has undergone a new paradigm as a result of BIM. BIM provides value for AECO/O organizations that intend to increase efficiency through technologies by accelerating the efforts to digitize existing processes. It is constituted by technology-led processes that offer several opportunities to improve decisions during the Design, Construction, Handover, and Operation of built assets. BIM is appointed as a major player in the Design, production, and management of digital information in the AECO/O industry by providing the information groundwork needed for a collaborative process (Bolpagni *et al.*, 2022)

When the subject is construction-related data, it is not possible not to mention BIM. BIM can act as a *data pool* tracking data from the beginning until the end of the BIM process. Information gathered within the BIM model enables a deeper understanding, leading to constant improvement, and starting a learning cycle for the building facility (Vasey and Menges, 2020).

Recently, Succar and Poirier, (2020) presented a holistic and conceptual view of delivering and managing digital and physical assets through the LITE (lifecycle information transformation and exchange) methodology - Figure 10. It connects Design, construction, and operation stages, through available resources and methods, always relying on information actors, who have the managing role. The cycle starts at the Design stage, executing activities to deliver digital assets, which will become physical assets in the upcoming stage. Those are prepared for the in-use stage, digital and physical get combined, ending the cycle. Regarding the information requirements, the authors establish model, document, and data uses in the beginning; followed by models, documents, and data sets; to buildings, systems, and components; ending with spatial, functional, and performance specs.

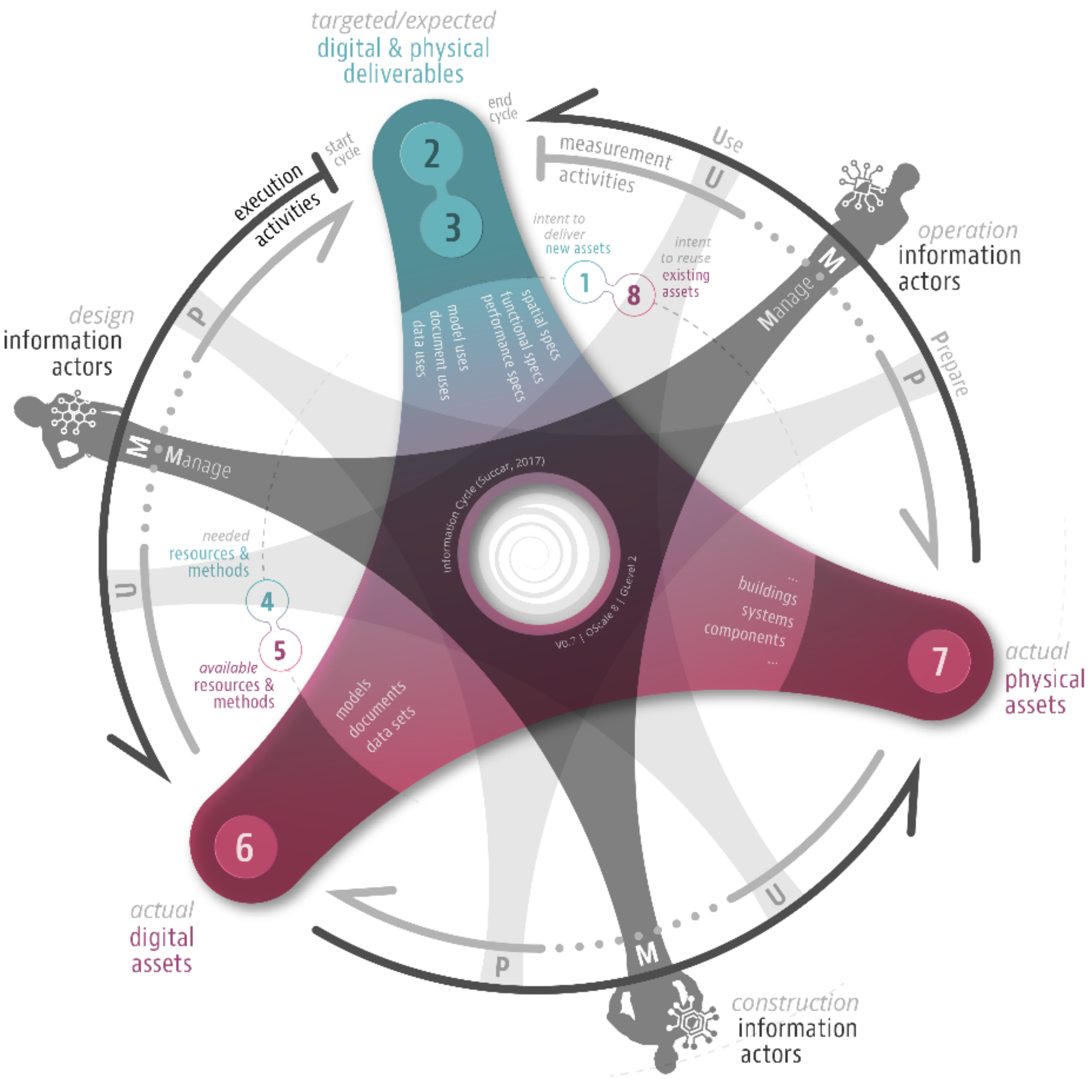

Figure 10 – Information Cycle Model – (Succar, 2020)

Efforts are being made to integrate information statuses, states, milestones, flows, gates, routes, loops, actions, and tiers across an asset's lifecycle. For defining, maintaining, and integrating project and asset lifecycle information, the Lifecycle Information Transformation and Exchange (LITE) laid the groundwork. Prior reactive practices are now becoming predictive practices, by using digital information and available technologies to improve processes.

2.2. BIM Dimensions and Information Lifecycle

When assessing BIM Dimensions, literature is not consistent and it appears to be a lack of consensus on what should be defined after the 5D, being hard to clear out these definitions. (Charef *et al.*, 2018; Koutamanis, 2020; Piasseckienė, 2022) Online platforms that distribute BIM knowledge also show disaggregation regarding the provided information, as illustrated by Figure 11.

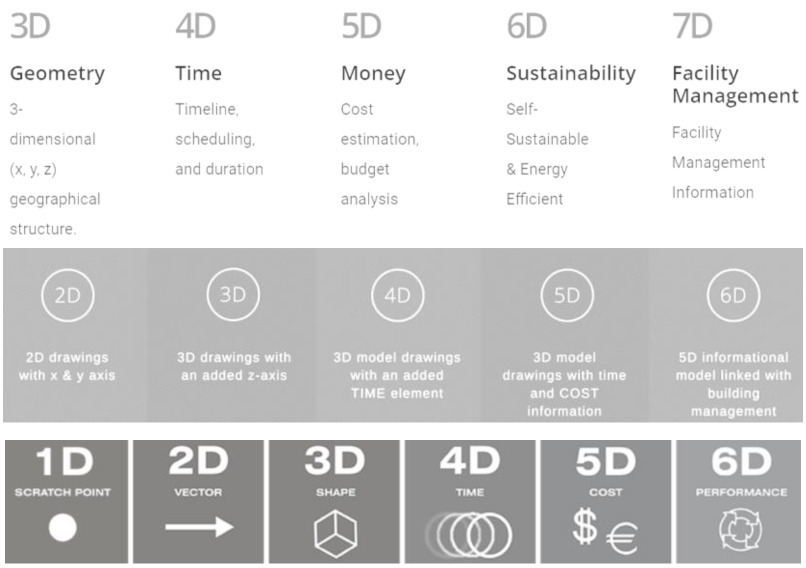

Figure 11 – BIM Dimension definitions according to different online platforms from first to last row, correspondingly, (3D Repo, 2021; Construction Lifecycle, 2018; SkyTop, 2018; United BIM, 2020)

A study conducted by Charef *et al.*, (2018) assesses the definitions found in literature *vs* the industry key players (Directors, Technicians, and Academics) literacy about BIM Dimensions. The author found more discrepancies between academics, rather than the enquired professionals, who seem to agree on the elements belonging to the dimensions – Figure 12. The enquired agrees mostly on the 4D for scheduling and 5D to cost estimation, while FM appears both on 6D and 7D. Nevertheless, sustainability is recognized as the topic for 6D.

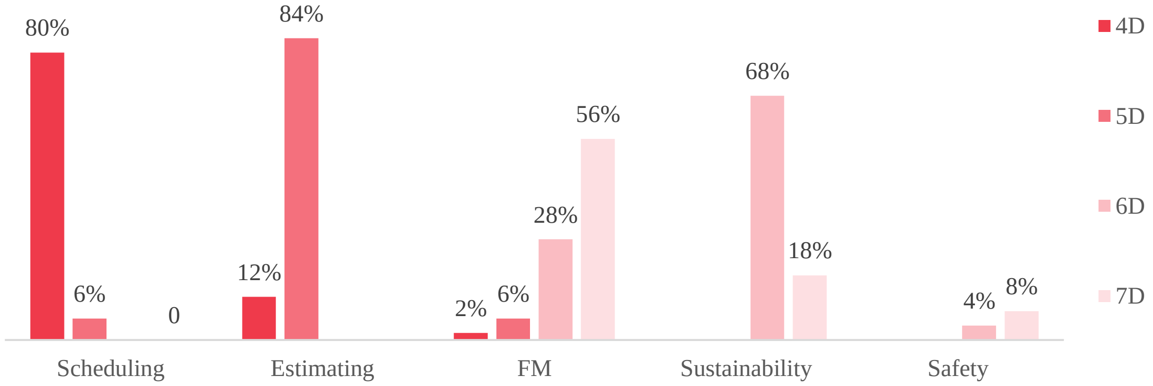

Figure 12 – BIM Dimension Element agreement – (Charef et al., 2018)

BIM dimensions awareness and utilization amongst professionals are inversely proportional to its nomenclature, as can be seen in Figure 13. As the dimension increases, the knowledge amongst the industry decreases.

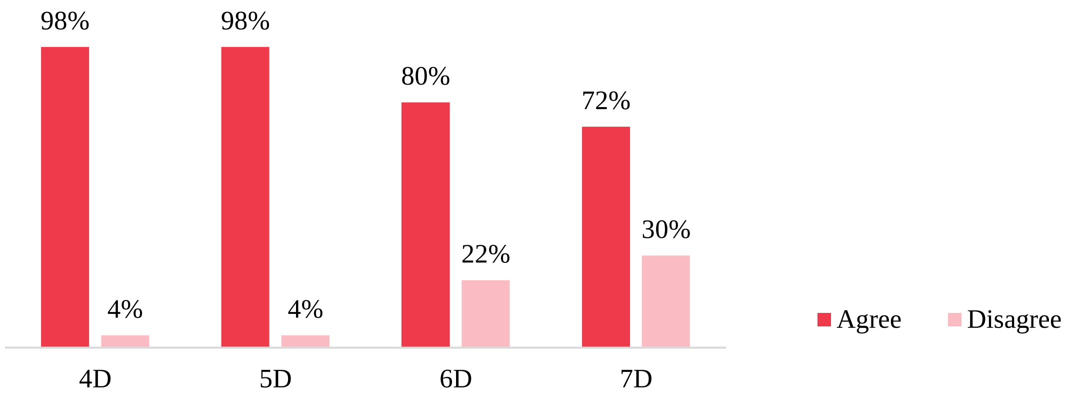

Figure 13 – BIM Dimension utilization – (Charef *et al.*, 2018)

In recent research, Piasseckienė, (2022) enlarged the theme's examination by identifying modern terminology found in literature up through the 10D BIM (Figure 14). The author struggles to find homogeneity in the elements proposed by different sources, concluding by presenting numerous shared definitions found. 1D BIM is conveyed to process management, 2D BIM to modelling, 3D BIM to three-dimensional modelling, 4D BIM to construction scheduling, 5D BIM to cost planning, monitoring, and control, 6D BIM to sustainability and energy efficiency, 7D BIM to building management, 8D BIM to accident prevention, 9D BIM to LEAN in construction and 10D BIM in industrialized construction. Another interesting relation proposed is the that the building representation interactions decrease through the dimensions, meaning that usually geometry stabilizes around the 3D/4D, while the information used by third parties increases, mostly from the 5D on - Figure 15.

Figure 14 – BIM Dimensions as referred to in the majority of literature –based on Piasseckienė, (2022)

Figure 15 – BIM Dimensions relation to the building representation and information used by third parties –based on Piasseckienė, (2022)

(Pärn *et al.*, 2016), also establishes a parallel of the dimensions with the stakeholder impact – Figure 16, supporting the previous correlation.

Dimension of development	Descriptions	Stakeholder impact
3D	Consists of two and three dimensional model data to represent the building design. 3D BIM can also be defined as: "*geometric presentation, parametric descriptions and legal regulations associated with the construction of a building*" [70].	Design team, supplier
4D (3D + time)	Links scheduling/time related information to the 3D model's objects in order to sequence the construction process over time [65].	Contractor, sub-contractor
5D (3D + cost)	Adds cost related information to the 3D model's elements. This enables early cost estimation and quantity take offs directly from a single 3D file (ibid.).	Quantity surveyor
6D (3D + FM)	Integrates FM and building lifecycle information. 6D is related to asset information useful for facility management processes, but after 5D no general consensus on the dimensions has been reached in the literature (ibid.).	Facility manager, building owner
nD (3D + ...nD)	Other possible dimensions associated with the BIM model.	Can relate to any specified stakeholder.

Figure 16 – BIM Dimensions and relation to stakeholder impact (Pärn *et al.*, 2016)

Koutamanis, (2020), considers a different approach, arguing that words and taxonomies are being misused amongst building information, as a dimension should be present among the basic features of each symbol as opposed to applying to BIM in a conceptual, generic sense. As indicated by the author, BIM dimensions stop at 4D, as any dimension greater than 4D refers to the ability to compute different aspects based on symbol characteristics in a 4D BIM.

Despite opposing positions that can be found in the literature regarding the elements to consider, or the open debate on what each should be from the 6th ahead, it is consensual that the multiplication of the dimensions might help the gauge how well integrated environments like BIM can function. BIM dimensions are used as a connection to project stages, maturity levels, design stages, and information lifecycle in the BIM process. (3D Repo, 2021). The scope of this work may be framed in the 7th dimension of BIM since it is closely tied to the FM phase, supporting the definition of most authors, and helping to standardize notions.

2.3. BIM for Operations & Maintenance and Facility Management

2.3.1. The value of BIM in O&M/FM

The term Facilities Management (FM) was early described by Spedding and Holmes, (1994) as a wide range of user-related properties and functions gathered for the good of the company and its staff. The author's intention while stating this was to suggest that FM is a broad field that can on occasion become abstract in its purpose, as complementary definitions can be observed through the literature.

> "(…) *a supporting **tool** to obtain sustainable and operational strategy for an organization over time through management of infrastructure resources and services"* (Nutt, 2004, p.462)

> *"(…) the **process** by which an organization delivers and sustains support services in a quality environment to meet strategic needs."* – (Alexander, 2013, pp.11-18)

> *"(…) an **integrated approach** to maintaining, improving and adapting an organization's buildings to promote a fertile environment that supports the organization's primary objectives"* (Pärn *et al.,* 2016, p.46)

The quotes above present a variety of complementary definitions, demonstrating to the reader how this field is evolving how through time, from the simplest concept of a *tool,* evolving to a *process*, aiming for an *integrated approac*h.

FM grew into an interesting study case, challenged by the high number of players involved, which leads to an intense fragmentation of the information since multiple sources generate data in parallel. Data has been commissioned as an organization's most invaluable asset. (Handzic and Durmic, 2015). It is reusable and plural, as the same data can be employed for distinct purposes or allocated to different applications. Accordingly, the ability to use useful data and information across the lifecycle of a building is therefore of utmost importance for efficient building management. As illustrated by Figure 17, FM consist of four key steps regarding information: acquiring, analysing, storing, and updating information. Gathered data should be analysed before stored, and finally, when need properly updated.

Figure 17 – FM relation to information – adapted from Mordue, (2018)

BIM shows higher adoption in Design and Construction stages, when compared to O&M – Figure 18. Plus, O&M reveals the highest percentage of non-BIM users, according to Becerik-Gerber *et al.*, (2012) Whereby the time the study was conducted, only 11% indicated to be in the process to adopt BIM in this work stage inside their organizations.

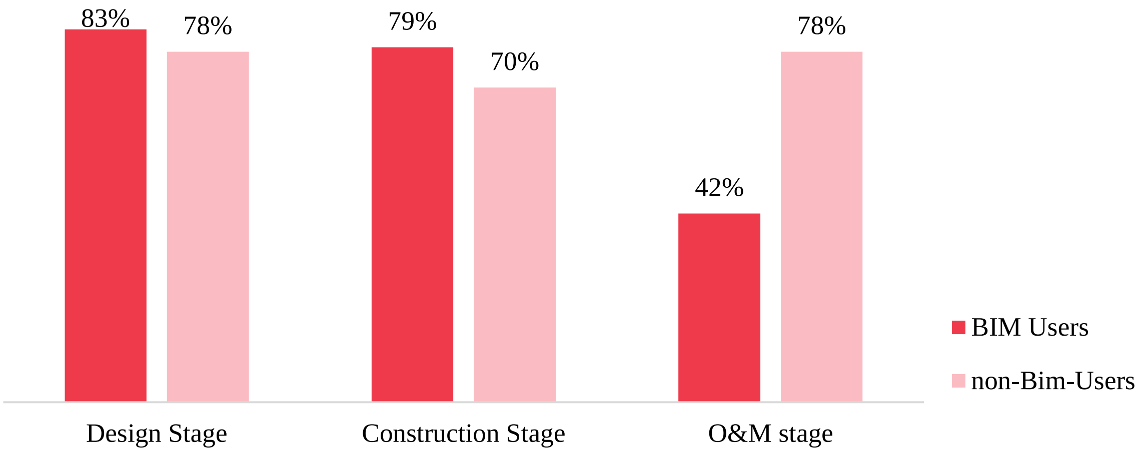

Figure 18 – Project stages where BIM is mostly used (Becerik-Gerber *et al.*, 2012).

Buildings are complex living organisms, which gather a vast amount of data. The FM sector can benefit from BIM merging three-dimensional visualization with critical product and asset data, providing a complete, dynamic, and digital environment to integrate, store, and share the information. Over 80% of FM time is spent in data hunting, consequence of dispersed data between different information systems and multiple and continuous manipulation by the involved parties (Becerik-Gerber *et al.*, 2012). Error-prone processes become a real concern, as data is not synchronized between systems. Facility management will not be an effective task without accurate as-built data. BIM introduces the idea of a single source of truth for all project information, simplifying data collection and enforcing the concept of a "data lake" or "data pool", where all stakeholders can consume and/or update information. (GSA, 2011).

2.3.2. Challenges & Benefits in O&M/FM

This limitation in BIM adoption inside the organizations can be explained by the multiple challenges that stakeholders go through while trying to move from a document-oriented practice to model-based, data-driven automated processes. (Shahzad *et al.*, 2022). The added cost of interoperability accounts for about 12.4% of the overall annual cost, according to a research conducted by the National Institute of Standards & Technology (NIST) in the United States. By deploying proper BIM-FM integration, the Return on Investment (ROI) can increase around 64%, within approximately 1.5 years of payback. (Teicholz, 2018). Over the last decade, authors have been identifying multiple challenges that BIM integration in FM raise, reflected in Figure 19.

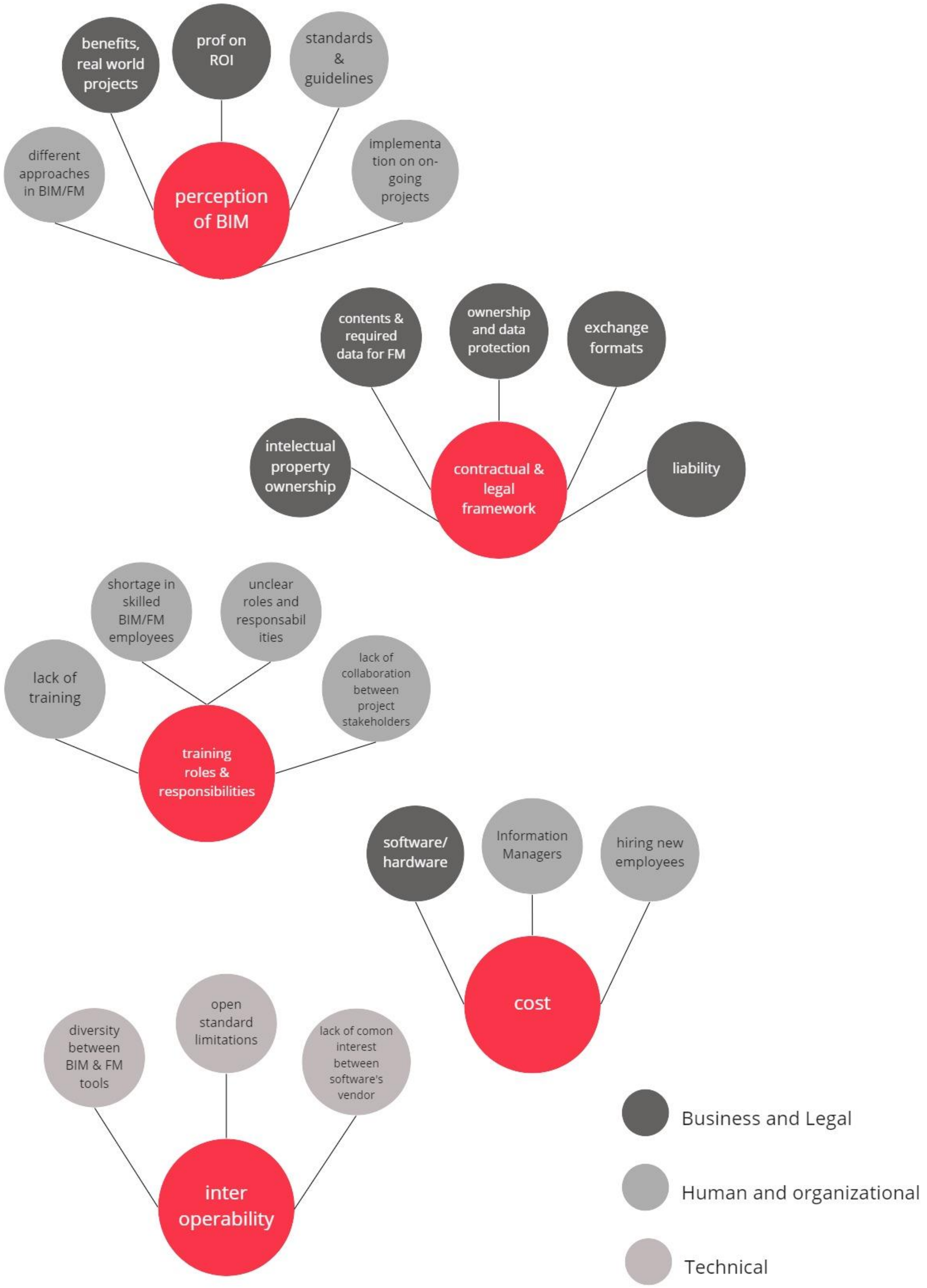

Figure 19 – Major challenged modules by BIM-FM integration

Over the last decade, authors have been identifying multiple challenges that BIM integration in FM raise. (Becerik-Gerber *et al.*, 2012; Dixit *et al.*, 2019; Farghaly *et al.*, 2016; Kelly *et al.*, 2013; Mcauley, 2016; Pärn *et al.*, 2016; Patacas *et al.*, 2020) are only a few examples of researchers, who synthesized challenges and benefits from BIM integration in the Operation and Maintenance/Facility Management phase. Overall, technological, and organizational barriers constitute the main groups, which have been sub-grouped into smaller clusters over time. According to the reviewed literature, challenges are now clear and pointed out quite often, while the benefits are still not identified by all the authors, as in Farghaly *et al.* (2016).Three main types of issues were used to characterize the barriers type, being Business and Legal, Human and Organizational, and Cost, corresponding to the grey shades in the figure below. Those are distributed across four main challenge types – perception of BIM, contractual and legal framework, training roles e responsibilities, cost, and interoperability. Inside these clusters, three main barriers can be found: Business and Legal, Human and Organization, and Technical. The author moved then into identifying the best linking approaches between BIM and FM considering the previous barriers but does not perform any critical assessment on the possible benefits.

More recently, Dixit *et al.* (2019) went deeply into the BIM-FM barrier subject, by conducting a review where an extensive list of studies developed in a nine-year range, from 2008 to 2017 was presented. The literature was grouped according to the reported issues connected to BIM-FM integration. This method was combined with a survey of FM professionals, which allowed comparison and identification of persistent issues. The four main modules identified were BIM execution and information management, Technological, Cost-Based, and Legal & Contractual.

Nevertheless, it is relevant to mention Bosch *et al.* (2015), who present a different approach, arguing that the most significant of all is mostly a consequence of all the previous described, consisting of the lack of a supply–demand chain in this field, as owners and operators are still sceptics about it since limited evidence of tangible benefits can be obtained from this integration. This position is further supported by Pärn *et al.* (2016), who state incongruence within supply and demand as a key obstacle to BIM-FM integration. What the authors suggest is the fundamental role of the customer as an informed stakeholder who sets his requirements. This position thus generates action on the part of the industry, which will have to speed up the production of elements to respond to its requests.

Despite the presented challenges faced by all the involved parties of the AECO/O industry, owners and operators should get specially thrilled when thinking about their investment in BIM. More than the short-term motivator, consisting in the reduction of costs in O&M, the long-term goal highlights an increase of the ROI, as indicates general value and application possibilities to perceive present FM operations and prospective BIM application areas firstly mapped by Becerik-Gerber *et al.* (2012) (Figure 20) and ehanced by (Dixit *et al.*, (2019) (

Figure 21).

Technological improvements relate to possible integrated and built-in features of the platform based on BIM data; logical tree organization of the model, with faster data search and retrieval; better maintenance, powered by more accurate clearances and specs and better controlling and monitoring with environmental indicators. Despite the property of a digital asset representation is connected to the technological cluster, it can also be understood as a complementary service, generating organizational value, and triggering market highlight by showing Information Technology (IT) progress. All these actions demonstrate focus on technical leadership and increase the company's visibility within the sector.

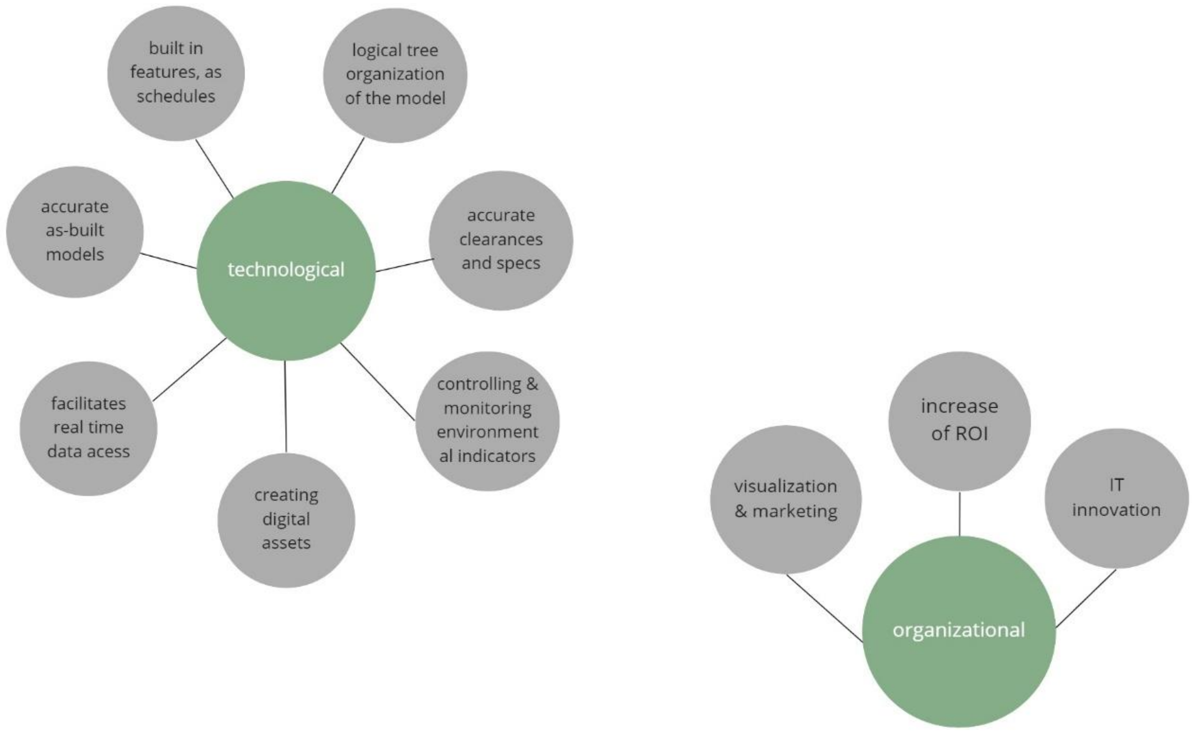

Figure 20 – Major benefits of BIM-FM integration – based on Becerik-Gerber *et al.*,(2012)

Dixit *et al.* (2019) complete their analysis by mapping the previously stated issues to key players, phases, suggestions, and benefits, with special emphasis on the last ones, arguing that by adopting BIM in the FM phase, one guarantees that BIM is utilized through the entire building lifecycle, while enhancing collaboration and adding value to the company.

Benefits of BIM-FM integration represented in

Figure 21, are dived amongst four categories, technological, BIM execution and information management, cost-based, and legal and contractual. In the technological cluster, two main advantages can be found regarding data, where the second one– increased data quality – can be perceived as a consequence of the first one – preventing data disintegration and fragmentation. Less fragmented and dispersed data corresponds to better data. Also, better processes are among the advantages, such as standardized information workflows, better communication amongst involved stakeholders, and better track, retrieve, and access of the information, all of them allowing for an overall save of time.

BIM execution and information management focus on data quality as it reduces information lost. Information retrieving in one single source also constitutes a timesaving factor, when compared to manually archived data entries, allowing for faster decision-making as all the information is available in one single location. One single source of truth is associated with cost-based benefits, by saving storage space. Legal and contractual fields can also benefit from this integration, as it will allow smother workflows by enabling faster verification processes and significantly decreasing paper-based processes.

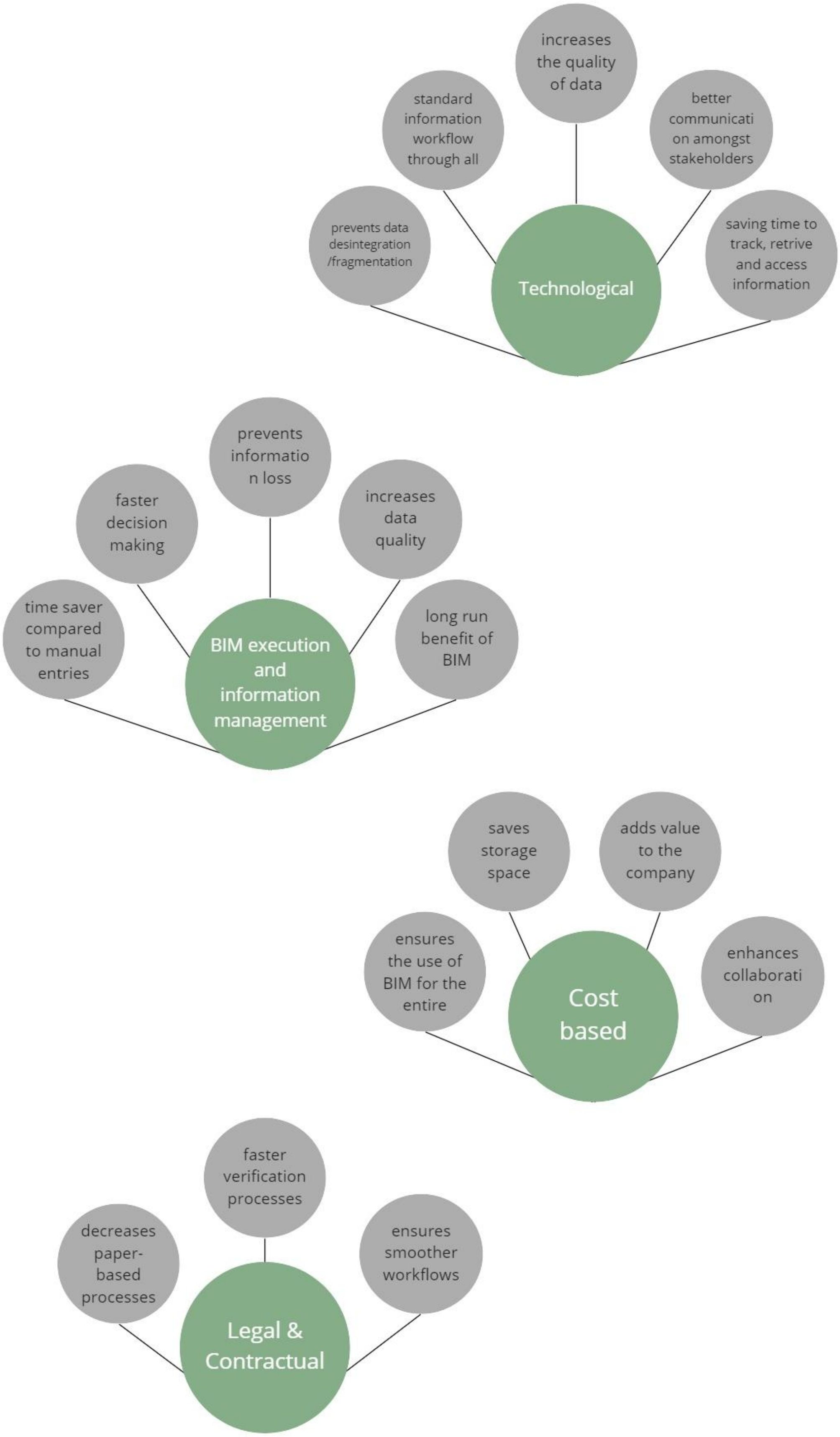

Figure 21 – Major benefits of integrating BIM in FM – based on Dixit *et al.*, (2019)

2.3.3. The lack of a structured framework in O&M/FM

As earlier identified in the previous sections of this dissertation, there are several challenges inherent to the purpose of BIM methodologies in the FM phase. From the carried-out analysis, the idea remains that one of the heaviest setbacks to BIM adoption throughout later stages of a facility lifecycle is the absence a structured framework for the O&M phase. The shortage of structured processes remains one of the most discussed topics in the literature, where the requirement definition, along with roles and responsibilities regarding data maintenance remains unclear. (Kelly *et al.*,2013).

Such a problem can be justified because of the reduced readiness of designers to prepare assets for future maintenance proof life. FM incorporates multidisciplinary activities which come along with extensive and diverse information requirements. Design phases have been the main target of research regarding the management of structured (i.e. graphical and non-graphical) and unstructured data (i.e. documents), leaving Construction and In Use stages behind. (Patacas *et al.*, 2020).

The adoption of BIM in the FM sector remains in its advent, due to the lack of an efficient methodology to integrate the information. The real use of BIM in the O&M is not totally disclosed, and even strong public entities like American organizations who had been pioneers in BIM implementation are still shy to deploy BIM for FM. (Codinhoto *et al.*, 2016)

Although the industry has recognized the need to develop asset management standards, and there has been an evolution in their development, the number of publications for the Design and Construction phases is still higher, where the standards available for the Design phase exceed those available for the O&M phase, which are not always connected to BIM, as visible in Figure 22.

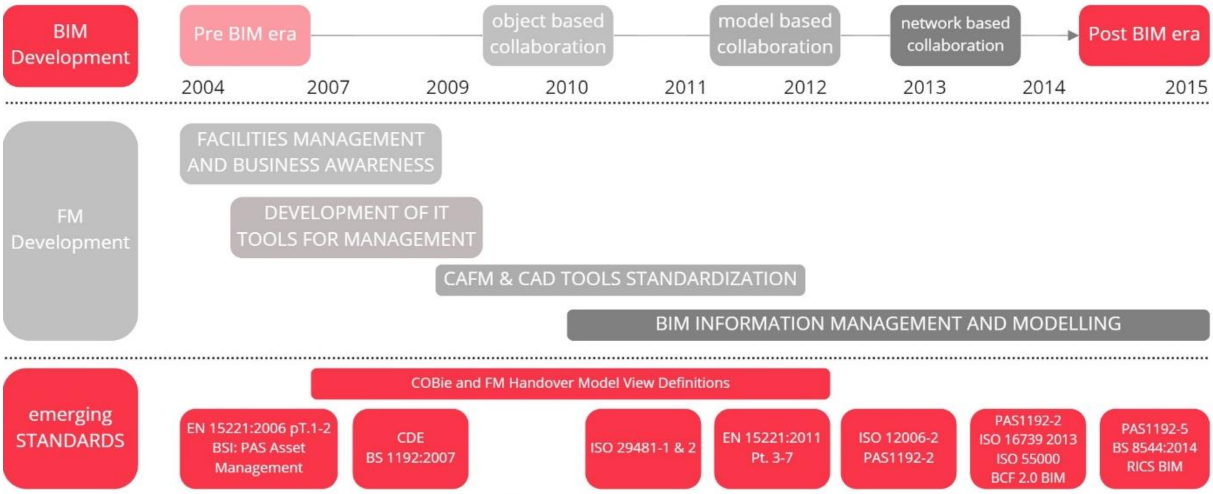

Figure 22 – Timeline relating BIM-FM development and standards adapted from Pärn *et al.*, (2016)

Information is essential to enable daily operations and efficient building maintenance, however, besides the digital era eases information capture, share, and retrieval, knowledge caption is still limited in the FM sector. Design and Construction teams are doing efforts, to assist FM teams with information. However, FM terminology is vast, which complicates the understanding of the needed information. This factor, along with unclear roles and responsibilities along the process, blocks the possibility of taking full advantage of BIM adoption in later stages of the building lifecycle.

2.3.4. The need for a structured framework in O&M/FM

Identifying the required BIM data outputs for FM systems is essential, while representing a key barrier to BIM business value realization. Investing in appropriate interoperability could significantly reduce maintenance costs and provide value later in the lifecycle.(Becerik-Gerber *et al.*, 2012)

In the latest years, BIM is being pointed out as a facilitator. BIM allows to organize, transmit, and save object's data with all its properties through the object lifecycle (Bolshakov *et al.*, 2020). Not only Industry is moving forward, but also facilities are getting more sophisticated. Therefore, there is a need to rely on accurate information (Matarneh *et al.*, 2018) Nevertheless, information discrepancies are easily found, from as-designed to as-built and as-is facilities. Provide accurate data recorded in an as-built BIM for usage in life cycle management is still an obstacle for the AECO/O industry to surpass.

In the Design phase, the major concern is to solve the clashes amongst subjects, being time and resource-consuming, leaving no moment to deploy new features in the traditional processes, which leads to a manually conducted information handover (Pärn *et al.*, 2016). Most of the current practices include manually harvesting information and re-entering it in computerized information systems, leading to redundancy in the supply chain and consequent additional costs. BIM could be seen as a suitable tool as information is easily accessed and retrieved by visual recognition of the asset located within the building, contributing to the overall decrease of time and resources associated with the management of a database.

Once the operational phase of assets is the main contribution to the lifecycle cost of the building, BIM adaptation to FM offers a valuable opportunity to store valuable data for asset maintenance. From all the vast amount of information generated during all the project phases, it is pointed out by Lavy and Jawadekar, (2014) that the operations and maintenance phase includes the most valuable information, as it can lead to higher levels of efficiency, such as reduced time for renovation, increased end–user satisfaction, optimized operations and maintenance, and reduced energy consumption.

Therefore, a subset of tangible, streamlined BIM data-driven guidelines for O&M becomes a true need. Research should focus on exploring versatile and approachable tools, company-suitable templates, concrete roles and responsibilities and tangible information requirements for effective data transfer. Providing teams with comprehensible procedures will allow further normalization of the nature, structure, and level of detail of the information to be shared amongst involved parties.

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3. INFORMATION REQUIREMENTS AND SAAS FOR FM

Overall, this chapter aims to identify and systematize the information available in existing documentation oriented to the life cycle phases of the building, as well as analyse and document existing software features, so it will be possible to acquire a broader understanding of the information needs for the performance of the facility management task. For a better understanding and contextualization of the aforementioned project phases, the Royal Institute of British Architects (RIBA) Plan of Work stages and correspondent colours will be used as a reference, since it constitutes a clear reference[1].

3.1. Information within Asset Management

Information related to building lifecycles can be divided into two major groups, being Project Information Model (PIM) and Asset Information Model (AIM). These are directly connected with Design & Construction phases, where Capital Expenditures occur (CapEx), and Operational and In-Use phases and Operational Expenditures (OpEx) – Figure 23 – (Mordue, 2018). OpEx are a company's ongoing costs, whereas capital expenditures CapEx represent its major, long-term costs.Physical assets like as buildings, machinery, equipment, and vehicles are examples of CapEx, while wages, rent, utilities, property taxes, and the cost of items supplied represent a few examples of OpEx.

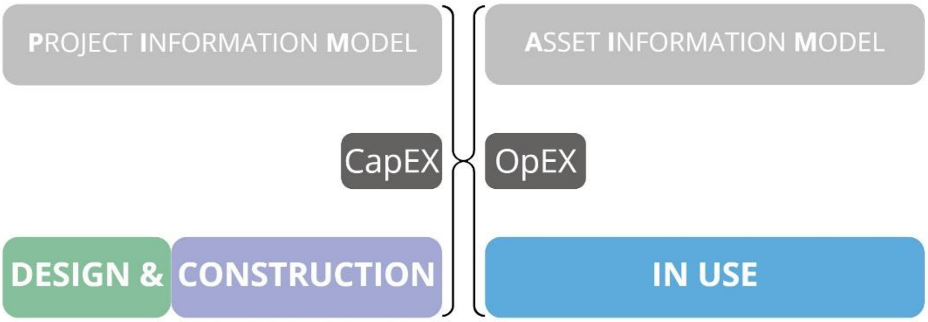

Figure 23 – CapEX and OpEX relation to Information Models – adapted from Mordue, (2018)

On an economical point of view, Facility Management supports Asset Management (Teicholz, 2018), so to achieve its main goal – maximum return on investment (ROI). As mentioned in earlier chapters, the AIM can benefit from the acquisition of information from BIM to be usable and transferable instead of being re-introduced in the upcoming AIM. While the PIM is a major repository for information, being continuously enhanced and kept up to date by the force of being a working tool, the AIM is only occasionally updated after the handover (Shahzad *et al.*, 2022).

3.2. Standards for Asset Management

Lu *et al.*, (2022) present three main groups of standards, being Asset Management related, BIM-related, and Data-Exchange and Interoperability within Asset Management and BIM aspects. Figure 24 illustrates a brief description of each standard content mentioned in Table **1**.

[1] (RIBA, 2020)See Appendix 1

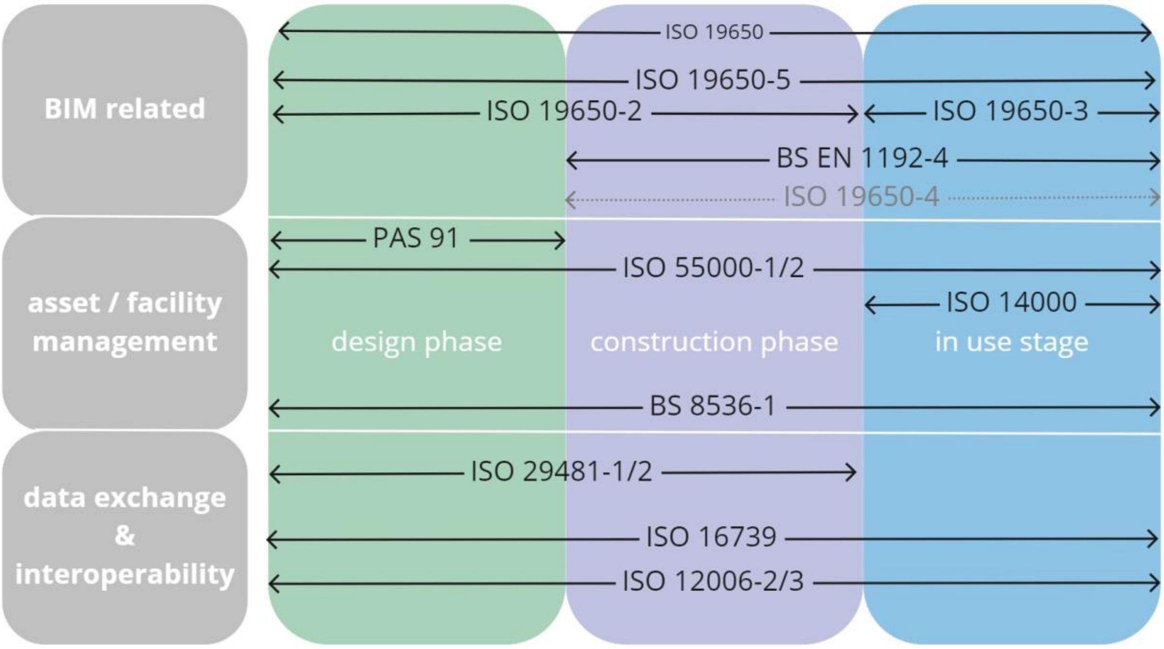

Figure 24 – Summary of standards throughout an asset's whole life adapted from Lu *et al.* (2022)

Table 1 –Standards related to BIM and FM

STANDARD	CONTENT
ISO 19650	organization and digitization of information about buildings and civil engineering works, including BIM - Information management using BIM
BS EN / PAS 1192	Specification for information management for the capital/delivery phase of construction projects using BIM
PAS 91	Pre-qualification questionnaire composed by standardized questions in order to help clients to define supply chains
ISO 55000	principles and terminology, and the expected benefits from adopting asset management
ISO 14000	environmental management systems
BS 8536	Design, manufacture and construction for operability facility management and asset management
ISO 29481	BIM Information delivery manual: methodology, format, interaction & framework
ISO 16739	IFC for data sharing in the construction and facility management industries
ISO 12006	building construction: organization of information about construction works – classification and object-oriented information (international framework for dictionaries)

Although a variety of standards can be found regarding asset management in general, a few are related to BIM, as can be seen in Figure 24, which relates the standards to the project phase to which they refer. (British Standards Institution, 2020; ISO, 2018; ISO/DIS_19650-4, 2019). ISO 19650, indicated in the previous table, was constructed by having the former BS EN / PAS 1192 as a foundation basis for all its chapters. The ISO 19650 is commonly considered to be the standard that fully covers the immediate needs of the Architects, Engineers, Contractors Owners &/or Operators (AECO/O) industry. Overall, the information provided remained equivalent, although some significant changes can be found. The first one consists of slightly modified terminology in use. “Supplier” was replaced by “Appointed”, “Client” by “Appointing”, “Contract” by “Supplier”, “Level of Information and Level of Detail” by “Level of Information Need” and “Employer’s Information Requirements” by Exchange Information Requirements”.

When considering ISO 19650, five chapters (parts) can be found – Part 1 is related to concepts and principles and the definition of information requirements. Part 2 establishes the roles and processes needed regarding information requirements, but only within the Design and pre-construction phase of assets. It also describes the BEP (BIM Execution Plan). Part 3 consists of the operational phase of assets, providing guidance to the CDE (Common Data Environment) and general method and procedures that support the team workflow. Part 4 will specify the procedures and criteria regarding information exchange, although is still under development. Part 5 encompasses security in the delivery and operational phase of assets and increases predictability by minimizing wasteful activities. (ISO, 2022)

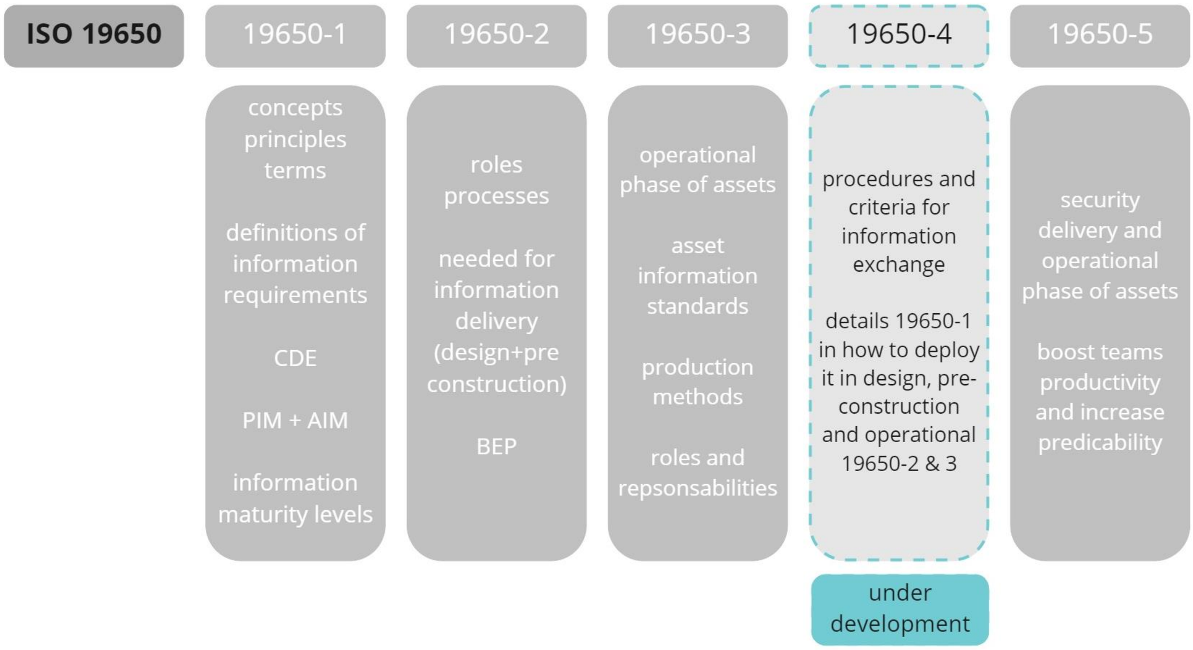

Figure 25 – ISO 19650 chapters summary

Another representative difference between the two standards refers to Part 4 – Asset Management. In BS EN 1192, part 4 specifically addressed COBie, being the title “Fulfilling employer’s information exchange requirements using COBie – Code of practice”. In ISO 19650, part 4 is still under development (ISO, 2022) and by the time this dissertation is being written, part 4 is only available as a draft, where COBie is only mentioned as an open schema/data format for “built asset orientated equipment and impact handover” (pp.11), not being specified in this part of the standard will include a further explanation about COBie, as it previous “parent” provided.

3.2.1. COBie within BS EN 1192-4

COBie was first published in 2007 and assumed as a part of the British Standard BS 1192-4:2014 later in 2014. (Pärn *et al.*, 2016) The aim was to create a standard to help the in distribution of data from the designer’s BIM model to the upcoming parties as contractors, facility managers and owners. COBie allows information to be prepared withoutany dependence on third-party applications or databases. Its use is broad, as it can be deployed from level 1 to integrated BIM (level 3), (Bew and Richards, 2008).

3.3. SaaS for FM - Overall Panorama in 2022

The 1980s were an important turning point for IWMS solutions, where the first CMMS solutions started to appear. Archibus, for example, was launched in 1983, followed by IBM Maximo in 1985. However, it was in the last three years that investment, merging and acquisition of solutions intensified, significantly powered by technological advances, IoT and open standards. (Trinquet and Clarke, 2022)

Before 2010, suppliers tried to evolve their solutions by adding modules. Software supported mostly FM functionalities, relying on manual interfaces and document uploads, while some platforms were already able to import data from BIM software. In the ten subsequent years, suppliers broaden IWMS solutions, by acquiring or establishing partnerships with other companies as Archibus, for example, acquired SpaceIQ, while IBM acquired Maximo. User experience started to be a top concern, as numerous vendors launched mobile versions of their software, such as Archibus, Maximo, Dalux, and Spacewell, among others. In the current time, new providers and acquisitions continue to appear to expand their operation to IoT and digital twin platforms. Currently, software is moving into integration with third-party applications, making building the technology ecosystem broader. Platforms are adapting to a data–centric approach, increasing the type of information supported as well as the readable file types, to fulfil the users' needs. Graphical, non-graphical and associated data in multiple files is also a concern when dealing with FM software – Figure 26.

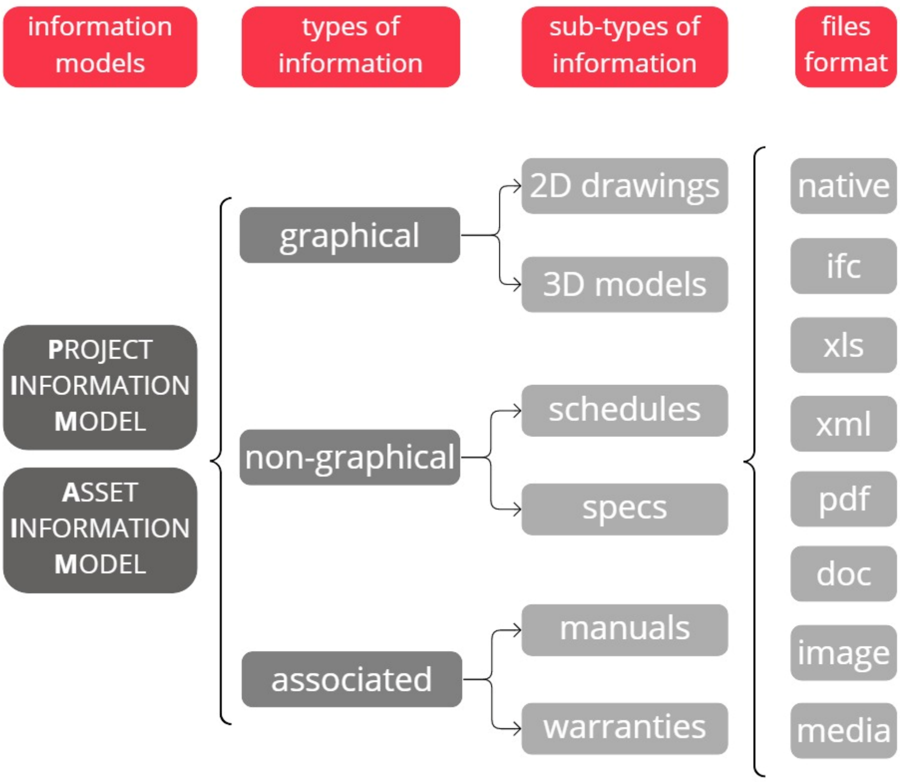

Figure 26 – Types of Information and models, adapted from Mordue, (2018)

3.4. Brief Glossary: Types of Digital Asset Management

Data needs to be understood by organizations as its most invaluable asset because it constitutes a vital prerequisite to implementing appropriate Digital Asset Management. The most common Digital Asset Management tools according to Pärn *et al.* (2016) are Computerised Maintenance Management Systems (CMMS) Computer-Aided Facility Management (CAFM), Enterprise Asset Management (EAM), and Integrated Workplace Management Systems (IWMS) – Figure 27.

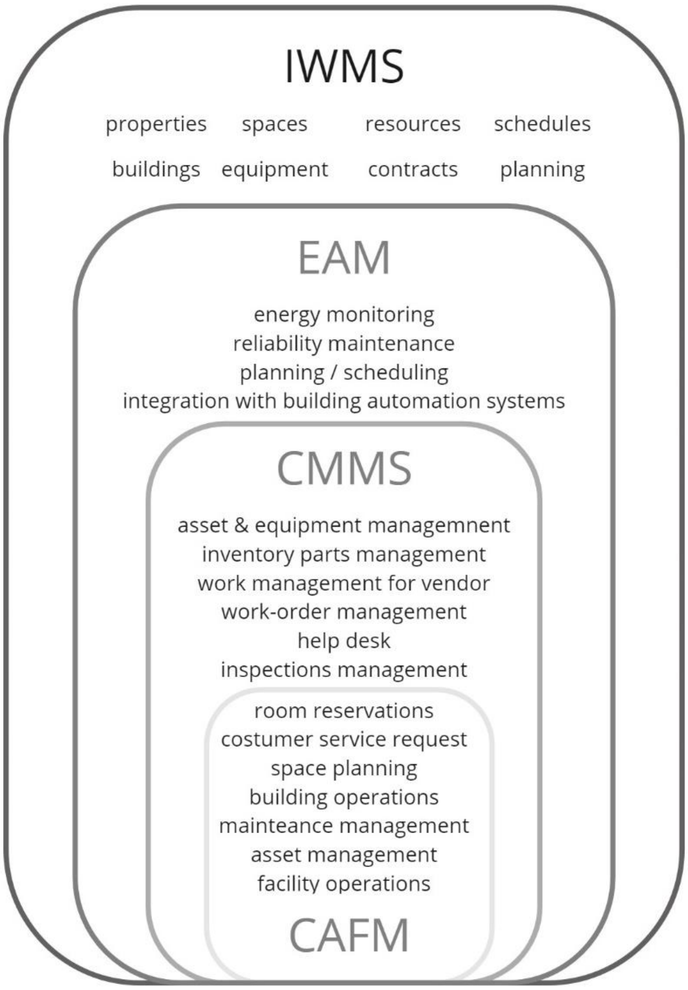

Figure 27 – Digital Asset Management types and enclosed properties

CMMS are tools focused on primary handling of facility management requests, regarding tickets and delegation of work orders. CAFM covers all the physical environment and everything in it, as it allows the creation of documentation, management of space utilization and distribution of work orders. EAM platforms act as a more in-depth system when compared to CMMS, as they go beyond the building itself and manage the assets within it, such as workstations, and computers, among others. IWMS is an all-in-one way to manage facilities. Its tools can go from real estate management to simple drawings assessment. It can be placed as the most inclusive tool in a facility manager's range of options. IWMS are similar to CAFM, just the first one is more appealing for large companies who demand to manage larger scale assets. Suppliers may use these terms in a non-consistent manner since it is also hard to draw the line between the concepts.

3.4.1. Non-extensive list of market solutions for FM

Regarding Software-as-a-Service (SaaS) for FM, consultancy companies have already reported on this topic, as Gartner (2018) and Trinquet and Clark (2022). Despite graphs and scores resultant from specific assessments, both present lists and a quadrant which separates the software options according to four different established capabilities. These reports focus more on the user experience regarding the software capabilities, rather than a comparison between software considering the modules they offer.

Gartner (2018) efforts go to CMMS solutions, where an extensive list of 335 software was presented, although only twenty-three were analysed and placed in the quadrant. To formulate extended conclusions, more extensive research on these 335 items would have to be conducted to enable the definition whether they are comparable or not, and research on the modules and functions provided to the user. The quadrant is divided into Masters, Leaders, Contenders, and Pacesetters, as represented in Figure 28. According to the report, Leaders are the most consistent products, with the highest market value, while Masters are highly valued by users. Contenders are focused on specialized services which can reflect an increase in the price, while Pacesetters are not so highly rated by their users. Maintenance Connection and Maximo are the top-rated solutions in this report.

Figure 28 – IWMS placed according to value and capabilites (Gartner, 2018)

Another report recently provided by Verdantix company – Figure 29 – (Trinquet and Clarke, 2022) focused on IWMS solutions, where thirteen software solutions were analysed, both with live stream demonstrations and questionnaires to the professionals. The selection criteria were to provide integrated solutions for facility and real estate management where revenue exceeds five million dollars. The workplace management systems were distributed in four major modules: Innovators, Leaders, Challengers, and Specialists. It is relevant to mention that the innovator's square is empty, and only two specialists were found within the scope of the report. Most of the included solutions presented as leaders, with Planon as the top-rated solution.

Figure 29 – IWMS placed according to momentum and capabilites (Trinquet and Clarke, 2022)

Under the scope of this dissertation, non-extensive research on the side of the user was conducted, to understand the available options and modules in the market and to review on the announced interoperability between authoring and FM software. The SaaS solutions presented in Table 2 (which can be consulted in better quality in Appendix 2 have some similarities with those pointed out by the reports, but not all of them overlap. It was not feasible to analyse them all within the limited timeframe of the dissertation, so the selection focused on nine solutions – Archibus by iOffice+SpaceIQ, Dalux Handover and FM by Dalux, Maximo by IBM, Tandem by Autodesk, 360Ops by Autodesk, Spacewell by Nemetcheck, ArchiFM by Nemetcheck, Planon Universe by Planon, and iTwin by Bentley (Archibus, 2011; Autodesk, 2022a; Bentley, 2022; DALUX, 2022; IBM, 2017, 2022; Iq Space, 2022; Planon, 2022a, 2022b).

The selection tried to include well-established and strong solutions such as Archibus and Maximo, which were two of the first FM software available in the market around the eighties, keeping their strong position through the decades, as shown in the previous reports presented. It was also significant to assess the biggest software houses, such as Autodesk, Nemetcheck and Bentley. Planon was one of the top-rated solutions by consultants and Dalux is growing in the European context in the last years, so those were also properties which were considered. Some features could not be confirmed to be offered at the time the research was conducted, being marked as not-available (n/a).

The main goal of this comparison was to assess interoperability and available modules, considering the different authoring software options. Most of the software vendors consider their solution as IWMS except Tandem, which can be considered an informative and descriptive platform for digital twins (Autodesk, 2022b). Integration with BIM Software relies on plugins, and when looking at BIM integration, only three revealed compatibility with Archicad, as opposed to the other six suitable for Revit. Multiple solutions are web-based and can offer a mobile version, even if it is not the full version with access to all features.

The key features offered by these solutions regarding O&M tasks are similar in all the options and basic features as search, sort, grouping and favourites can be found across all the options. Another relevant feature is the possibility to import/export COBie, which is only available in four out of nine of the solutions. The others can read the information but do not allow manipulation inside the platform. Omniclass is the embedded classification in three of the solutions, followed by Masterclass and along customized schemas. Dalux and iTwin support immersive technologies, using associated modules or adding subscriptions to the package. Maximo and Spacewell are connected to IoT, allowing the permanent data input from sensors placed in the facility.

This brief overview allowed to understand that although the market offers a wide range of solutions, many work within their ecosystem and are not fully integrated with BIM authoring software. Information from the authoring software can be read and used within the FM environment but editing it in a functional and/or bidirectional way remains a non-linear process. To enable the user to maximize his knowledge and monetize the value invested in the software, specialized training, and experience from engaging with various procedures are needed. Because each software is so intricate and specific, the owner or operator should choose it in advance to prevent teams from having to cope with a variety of skills, knowledge, and particular insights of multiple platforms.

Aiming for enhanced interoperability, the FM industry could benefit from a more open and supplier free approach, where multiple involved parties could exchange information without being attached to one specific provider. The feature encompassing the integration of COBie export/import, which is already available in some of the solutions, could be an approach to overcome this limitation and improve the collaboration amongst involved teams, or even across an owner’s portfolio.

Table 2 – Digital Asset Management SaaS assessment

Vendor		iOffice+SpaceIQ	Dalux	IBM	Autodesk	Autodesk	Nemetcheck	Nemetcheck	Planon	Bentley
SOFTWARE		**Archibus**	**Handover, FM**	**Maximo**	**Tandem**	**360Ops**	**Spacewell**	**ArchiFM**	**Planon Universe**	**iTwin**
Integration with BIM Software		Smart Client Extension4	PlugIn	ModelStream	BIM 360	BIM360	MCS+Bimplus	Bimplus	Plannon Connect	AssetWise+PlanSight,
Interoperability		Revit	Revit, Archicad, Navisworks	Revit	Revit	Revit	Revit, Allplan, Solibri, Archicad	Archicad	Revit	Bentley Design tools, AVEVA, Hexagon, Autodesk
Type of SaaS		IVWS	IVWS	IVWS	digital twin platform	IVWS	IWMS	IVWS	IWMS	IWMS
Authentication		email+password	email+password	email+password	autodesk account	autodesk account	email+password	email+password	email+password	email+password
Devices		desktop, mobile	web-based, desktop, mobile	web-based, desktop, mobile	web-based	web-based, mobile	web-based,desktop, mobile	web-based, desktop, mobile	desktop, mobile	web-based, mobile
Features	Integration	bidirectional	still	biderctional	bidirectional	still	bidirectional	bidirectional	bidirectional	bidirectional
	Cobie Import	yes, through connector	yes	yes	no	no	no	no	yes	no
	Cobie Export	yes, through connector	yes	yes	no	no	no	no	yes	no
	Templates	yes	yes	yes	yes	yes	n/a	n/a	n/a	n/a
Basic Features	Search	yes	yes	yes	yes	yes	yes	yes	yes	yes
	Sort	yes	yes	yes	yes	yes	yes	yes	yes	yes
	Grouping	yes	yes	yes	yes	yes	yes	yes	yes	yes
	Favorites	yes	yes	yes	yes	yes	yes	yes	yes	yes
Classification		Masterformat,Omniclass	Omniclass	Omniclass, Uniformat, customized	Masterformat, Uniformat, Uniclass	connected to Revit categories/customized	imported from BIM	imported from BIM	n/a	n/a
Data /Power BI	Dashboards	yes	yes	yes	yes	yes	yes	yes	yes	yes
	Reports	yes	yes	yes	yes	yes	yes	yes	yes	yes
Requests	Tickets	yes	yes	yes	no	yes	yes	yes	yes	yes
	Tasks	yes	yes	yes	no	yes	yes	yes	yes	yes
	Checklists	yes	yes	yes	no	yes	n/a	yes	yes	yes
Equipment	Picture	yes	yes	yes	no	yes	yes	yes	yes	yes
	Model									
	Manufacturer	yes	yes	yes	no	yes	yes	yes	yes	yes
	Serial									
	Warranty	yes	yes	yes	no	yes	yes	yes	yes	yes
	Age/LifeExpenctancy	yes	yes	yes	no	yes	yes	yes	yes	yes
	Docs	yes	yes	yes	no	yes	yes	yes	yes	yes
	Maintenance History	yes	yes	yes	no	yes	yes	yes	yes	yes
Instant Communication	Call	yes	no	n/a	no	no	yes	n/a	n/a	n/a
	Message	yes	no	n/a	no	yes	yes	n/a	n/a	n/a
	Email	yes	yes	n/a	no	yes	yes	n/a	n/a	n/a
	Voice Record	yes	no	n/a	no	no	no	n/a	n/a	n/a
Recorded Activity	Add Comments/ Photos	yes	yes	n/a	no	n/a	n/a	n/a	n/a	n/a
	Tag People	yes	yes	n/a	no	n/a	n/a	n/a	n/a	n/a
Technologies	Immersive Visualization		yes	n/a	n/a	n/a	n/a	n/a	n/a	yes
	IoT	yes	n/a	yes	n/a	n/a	yes	n/a	n/a	yes
	Sensor Vendor API	yes	n/a	yes	n/a	n/a	yes	n/a	n/a	yes
	Use Stats	yes	n/a	yes	n/a	n/a	yes	n/a	n/a	yes
	Environmental Conditions	yes	n/a	n/a	n/a	n/a	yes	n/a	n/a	yes

4. AS-DESIGNED, AS-BUILT, AS-MAINTAINED

Vendors have already developed the essential three-step approach for data capable of increasing productivity and profit – specify, capture, and verify (Autodesk, 2022). This means that stakeholders should first define and organize the relevant data requirements to after seizing and validation achieve the best target outcomes. Project teams should be aligned when delivering data, by providing a consistent specification of assets, spaces, and systems to be managed in the future. Processes must be repeatable to create consistency, providing owners and operators with the capability to analyse data for their entire portfolio.

4.1. Types of Requirements

When delivering a project, the involved parties need to understand and be aware of the available tools and methods that guide and support BIM compliance. Requirements can be presented in many shapes, having distinctive characteristics, and developed at multiple levels. Policies, standards, guidelines, and protocols are examples of how to describe information regarding its formal shape, content, and level. Cavka *et al.*, (2017) establish five individual types of BIM requirements, based on their stiffness and level of implementation. Those are presented in the image below – Figure 30.

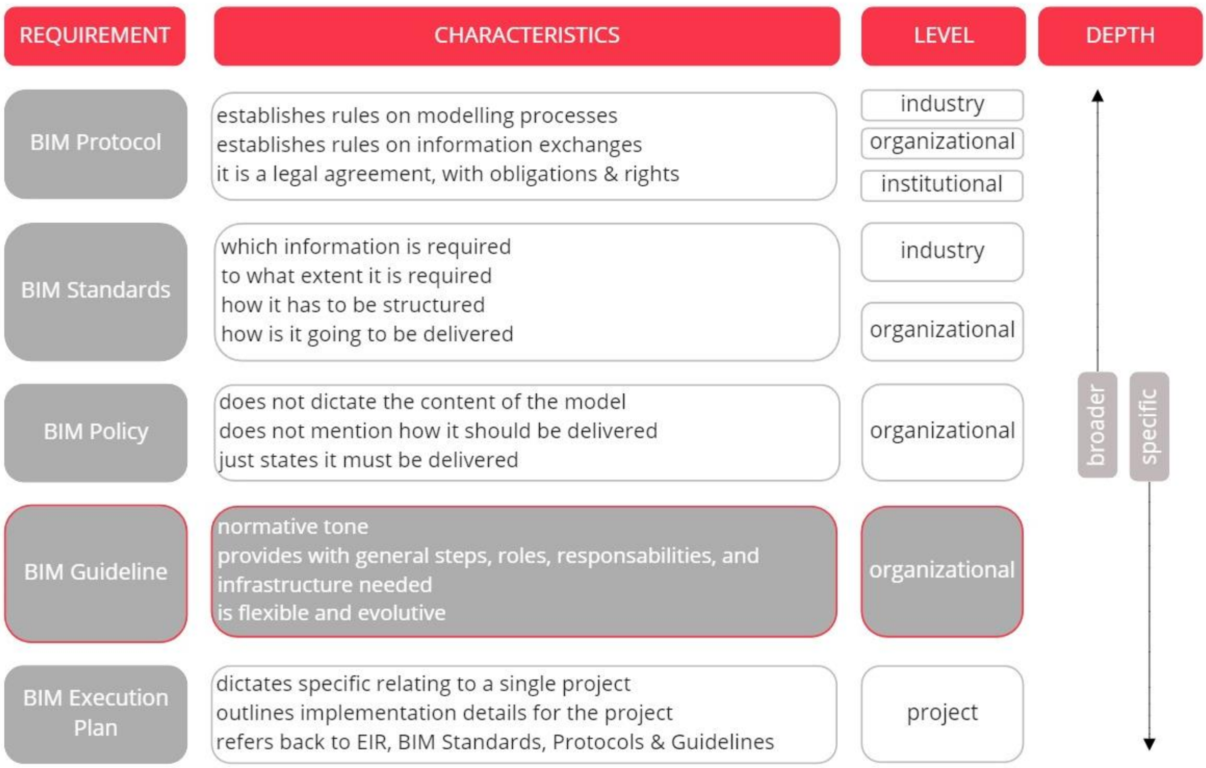

Figure 30 – Type of BIM requirements – based on Cavka *et al.*, (2017)

BIM Protocol and Standards may be the broader examples and are close in their definition. Standards ensure consistency, dictating how information should be structured and how it needs to be delivered Protocols also establish rules on information deployment and exchange, plus it acts as an additional legal requirement, creating obligations and rights to the involved parties. This places it not only at the industry and organizational level but also at institutional. Standards determine measurable outcomes, while protocols prescribe the rules to achieve those outcomes. The most particular of all the presented requirements may be the BIM Execution Plan, which is project-specific, as it relates to a single project, outlining specific details and connecting directly with EIR, organizational Protocols and Guidelines.

Policies are simply indicative documents, where the purpose is stated, (ex. deliver COBie in the Handover stage) although it does not provide information on how to reach it, so in other words, it does not provide any procedure in how to do it. Guidelines are user-friendly directives, which provide the end-user with general steps, roles, and responsibilities in how to proceed to achieve concrete results. As they explain processes, they should be flexible and evolve with the organization's maturity level, ensuring they adapt to its internal procedures.

Considering the main objective of this dissertation exposed before, the upcoming chapters' main objective is to act as organizational guidelines for COBie's deployment within the teams, adapted to the Portuguese context and tailored to meet the partner company expectations and experience. According to LIMSEN's data records on previous experiences and ongoing projects, having concrete information requirements with clear roles and responsibilities can save up to six weeks of meetings.

4.2. BIM-FM Linking Procedures

A BIM-FM integrated system can provide substantial advantages, as previously demonstrated in chapter 2. Overall, they contribute to lower the facility's total cost of ownership and provide continuous enhancements to the building. Buildings are a place of permanent change, where equipment is replaced, systems modified, and spare parts substituted. When an investment in BIM-FM linking procedures is made, it can provide an accurate record of the current situation and allow better decisions to be taken.

The straightforward, smooth link between BIM data and FM data is still an open discussion, highly affected by the challenges and barriers earlier described. Farghaly *et al.* (2016) presented four main approaches to surpass interoperability issues, assessing the pros and cons of each solution. Manual spreadsheets, IFC, COBie spreadsheet and Proprietary Middleware were the chosen methods of research, which can be grouped as they provide exclusively non-geometric data, both geometric and non-geometric, or customized – Figure 31.

Figure 31 – BIM-FM linking approaches data types – based on Farghaly *et al.*, (2016)

As illustrated in Figure 32, challenges and benefits can be found in the observed solutions. Regarding the familiarity to the end-user, BIM concepts such as IFC and COBie appear in the middle of the listed solutions, the first one being spreadsheets and the last and more complex proprietary middleware, colloquially named as software solutions. As exposed in the previous chapter, proprietary middleware options are proliferating across the O&M/FM industry. These solutions rely on software designed by a third party, which provides BIM to FM connection, mostly through a bi-directional link, ensuring the information is updated continuously. This solution, however, comes with an additional cost of preparation and implementation, as it carries the software cost plus the training of the involved team. It may also be prone to interoperability problems, as different proprietary middleware may not be compatible with each other.

IFC, as an open vendor-neutral BIM format and objected-oriented database, was very promising in this, however, O&M/FM applications needed to convert imported objects into native objects. As imported elements vary from natively produced ones, a perfect match is still not attainable. Plus, involved stakeholders do not always have access to IFC-compliant applications.

Manual spreadsheets are well known by the FM industry, which used them as a primary method to transfer paper documents into FM-compatible data. It may appear to be simpler and swifter in small projects, but it is a highly time-consuming process, which lacks a formal structure and where no data validation and quality control are conducted during the process. The only possible advantage to it is the fact that the teams are familiar with it, and do not need to introduce any changes in their working process.

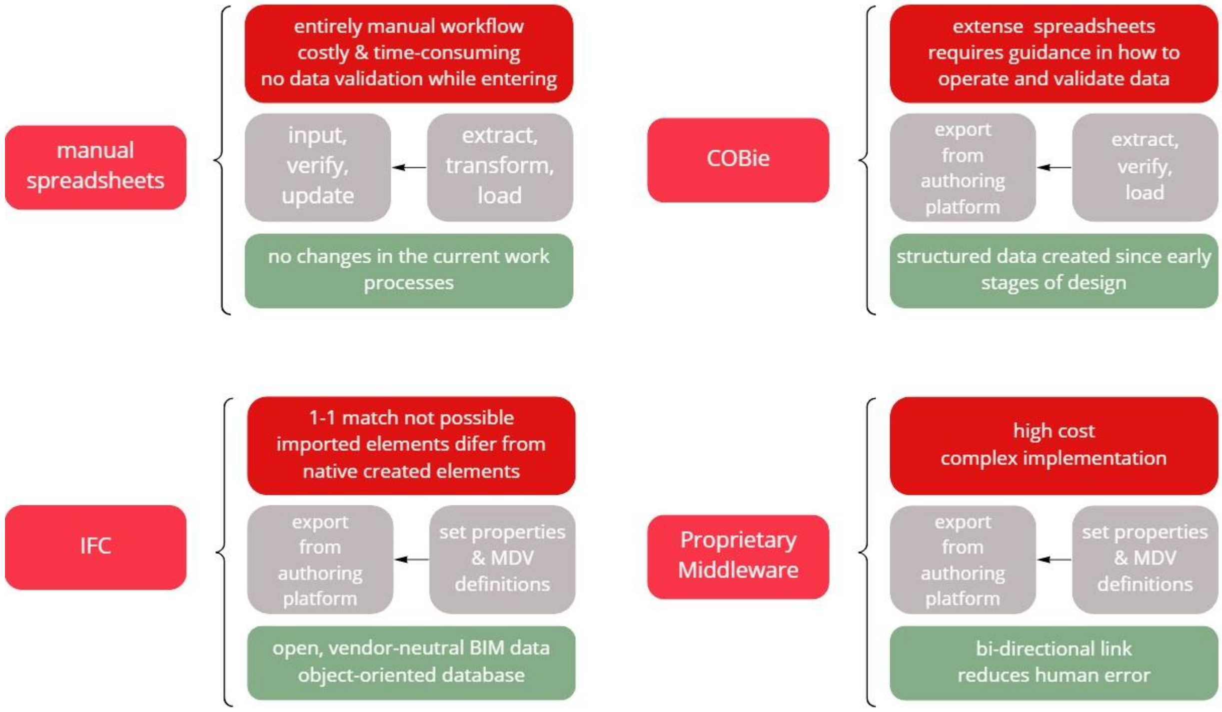

Figure 32 – BIM-FM linking approaches pros and cons – based on Farghaly *et al.*, (2016)

COBie offers similarities with both IFC and manual spreadsheets, being a vendor-neutral and open exchange standard, and capable of being shaped as a spreadsheet, providing a structured data delivery tool. (Yalcinkaya and Singh, 2019) . It can be used in from the initial stages of Design, however, involved parties find it very extensive to encourage and support its implementation. There is still a lack of mutual understanding of how to operate with it without missing any data entries.

4.3. COBie

4.3.1. Why COBie

COBie was developed by considering various existing FM-related standards, and it remains open and vendor-neutral information. COBie-based information can be presented in an IFC STEP Physical File Format, an IFC XML and a spreadsheet XML (open XML schema used by spreadsheet applications). When thinking about the complexity of the first two formats to the common end users, the spreadsheet becomes the most widely held approach for presenting and exchanging COBie data. Despite there is still room for potential improvements in the representation of COBie data in a more practical and useable manner, the COBie spreadsheet is an editable and person-readable format, allowing the user to take advantage of mathematical functions, sorting, and querying, that are familiar editing techniques. (Yalcinkaya and Singh, 2019).

As COBie is editable in a simple XML format, it is within easy reach of all the involved parties. It provides benefits for all the stakeholders involved in a project, being Designers, Consultants, Facility Managers, Contractors, and Owners, as it is a placeholder for subsequent interchange or retrieval, which can be used as a benchmark in contract documentation, such as BEP. One of COBie's main advantages is that it may serve as a general information source that all types of contractors, suppliers, and owners can use. As it is produced throughout the design and building phases, it has all the qualities to be a powerful and effective instrument to gather essential information to assist facility management.

Lavy and Jawadekar (2014) conducted a case study including three projects, where the preparation of COBie started after the construction phase and consequently, the information that was collected during early stages as Programming and Design could not be assembled. All the participating teams should be involved from the beginning, to enhance cooperation and interoperability. It may be challenging to meet this criterion because teams may not be defined at early stages, but an endeavour should be done to gather information since the beginning of the process, so it can be effectively used by building management systems and support FM operations.

Being BIM considered the portal to life-cycle FM (Lavy and Jawadekar, 2014), COBie can act as a tool for data bridge between both. It adds no cost to O&M as it a bi-directional tool that can be imported/exported from the BIM Model to the Digital Asset Management solutions, avoiding data re-entry associated cost and providing higher quality data. An owner is not tied to a single maintenance system in his portfolio, especially since different types of projects often require different maintenance systems.

The primary goal of collaboration, which is to exchange information between different teams, took the construction industry to rely more on and more on automated systems, which aim to increase productivity by reading and using information. Most of the information required for O&M is non-geometrical, as the geometrical component is only there to help the user to locate the assets. Not all data needs a model, nevertheless, it can still be modified and manipulated inside the authoring platform.

In the Design phases, the presence of geometric information is crucial, but as time progresses this need diminishes, while non-geometric information increases. Construction, on the other hand, is more complex, where both are required and essential – Figure 33.

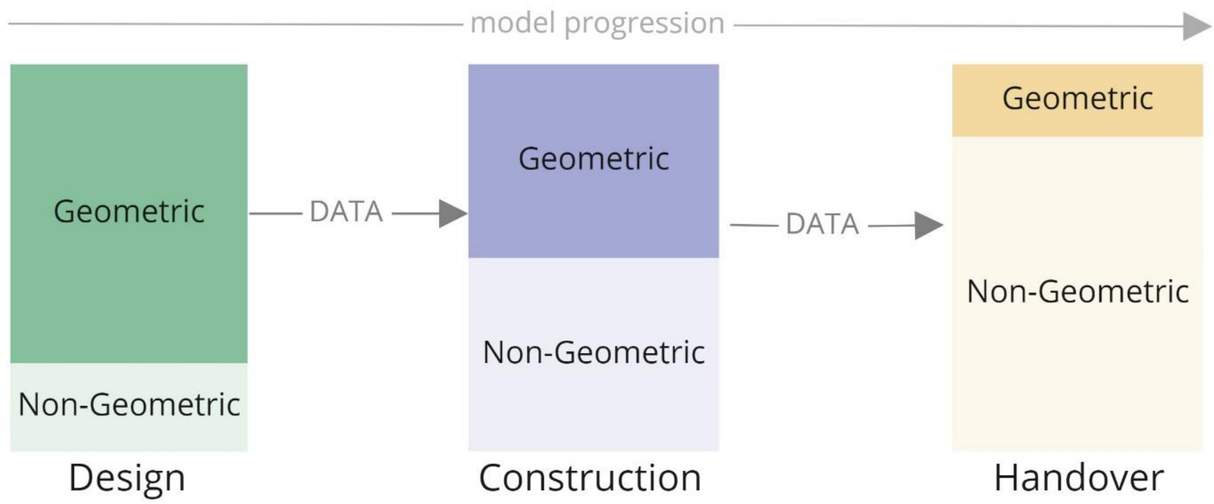

Figure 33 – Type of Data in Design and Handover Stages– based on East *et al.*, (2021)

Becerik-Gerber *et al.* (2012) claim that successful integration of BIM in FM processes will be endorsed significantly by non-geometric data requirements. When looking at the four previously described options, COBie spreadsheet stands out as the most aligned solution with what was presented previously, as non-geometric requirements allow broader integration within multiple Digital Asset Management solutions, along with being a user-known format.

4.3.2. Challenges with COBie

The creation of COBie deliverables is still problematic, not only in the Portuguese panorama but in the overall construction industry. According to Dixit *et al.* (2019), despite 86% of the building owners requiring BIM data from contractors, only less than 17% use it for effective FM purposes.

Misconceptions among the end-users lead to insufficient implementation and lower acceptance of COBie deliverables. The sequence Collect – Validate – Delivery can be directly correlated to the Owner, Designers and Contractors. The owner should be able to set the overall requirements, mostly to ensure a better return on investment (ROI), since it is their investment that is at risk. Owners can have the support of third parties, referred to as Information Managers within ISO 19650 or assuming the informal figure of BIM Consultants, Managers and Coordinator who have deeper knowledge and can provide valuable inputs about it. East *et al.* (2021) present a different vision, stating that the designer should provide the information, as it is its legal responsibility to provide for the built asset to function properly.

Identifying one single source amongst the involved parties can be challenging. Usually, COBie process – Figure 34 – starts with Design professionals being then passed to contractors and owners. Regarding spatial elements such as facilities, floors, or zones, usually, the designers provide information about it. When considering equipment, it may be not so linear, as it can have multiple teams involved. A shower tray, for example, is a concrete case where it may be not always clear if the data should be exported from architectural or plumbing models.

Ideally, collaborative work should be a sequence, starting with the owner defining the requirements, followed by the designers providing data related to the building, such as spaces and components and closing with the contractor who would work on top of a consolidated database, increasing it with more detailed information as a specification, installation, and maintenance data. The problem is that this process is rarely linear because the designers specify something that will have to be subject to the client's approval. If the client approves, the information is passed on to the manufacturer, and eventually, it can still be changed due to stock-outs, and price increases, among others. Therefore, significant effort relies on the contractor. mostly because of a lack of data fidelity from the previous stages.

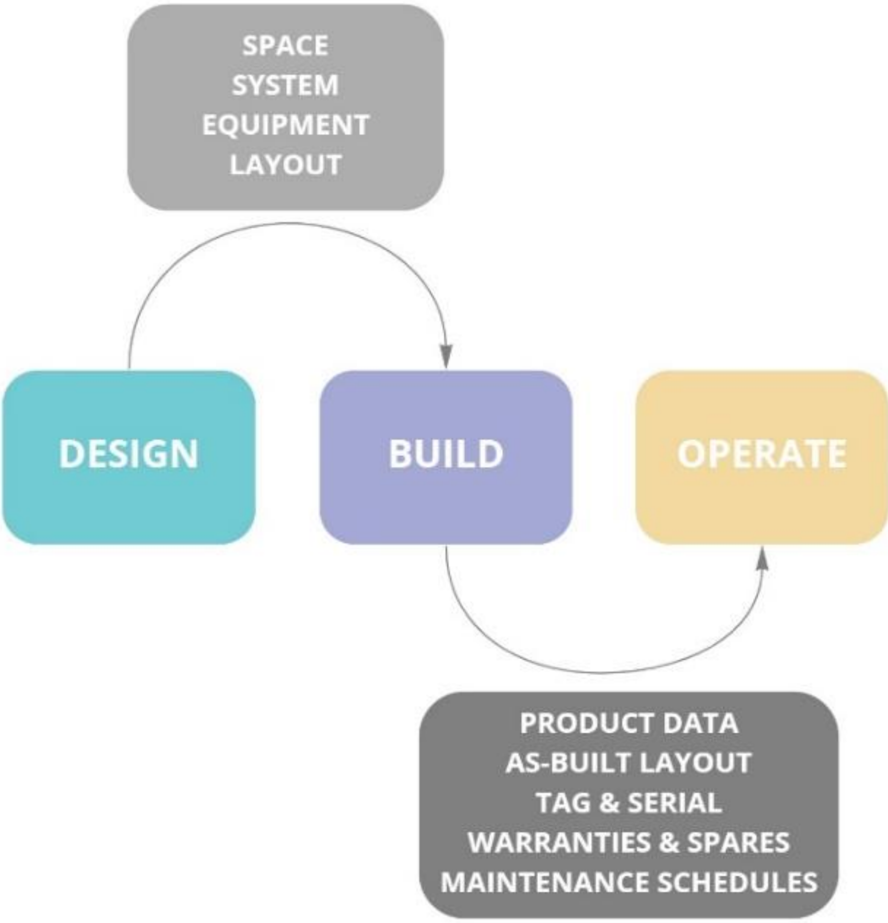

Figure 34 – COBie Process– adapted from East *et al.* (2021)

Defining the data to be provided and isolating the spreadsheets will help to reduce the cost of capturing data and refining which data is needed. (East *et al.*, 2021). Here remains one significant challenge, which is concrete information about responsibilities and roles within the different building stages.

4.3.3. About COBie

Although the project started in 2005, COBie was originally published by the US Army Corps of Engineers in 2007– Figure 35. One year after, commercial tests begin and by 2013, Autodesk launched Interoperability Tools, a built-in tool to fill COBie. One year after it became a requirement in the British code of practice BS 1192-4:2014 and it was also part of American national standards. In 2021 a workbook about COBie is published (East *et al.*, 2021). The upcoming version, COBie 2.5 is currently a work in progress by buildingSMART.

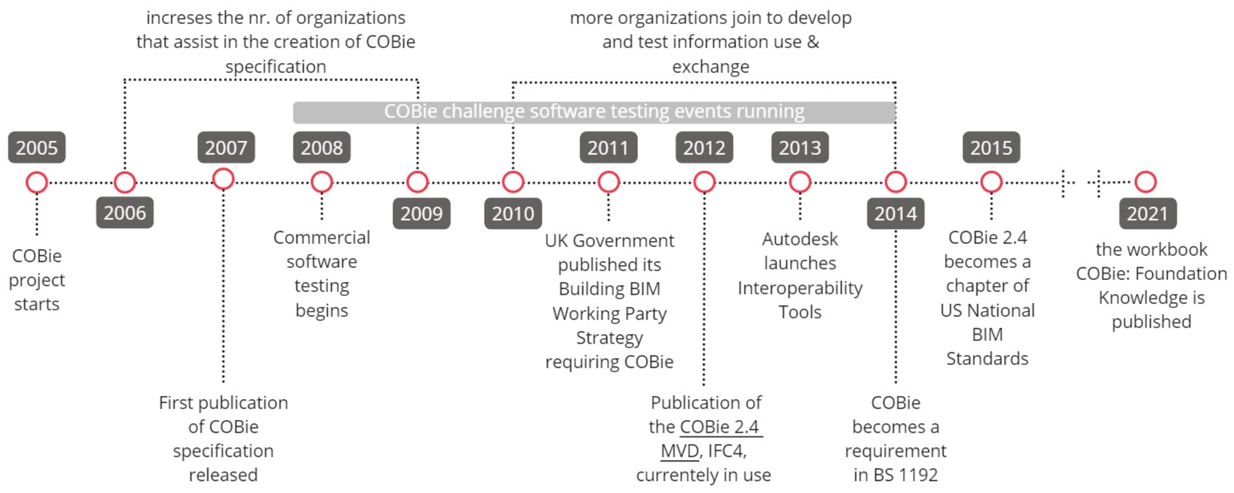

Figure 35 – Brief Chronology of COBie–adapted from buildingSmart, (2022); Spehar, (2016)

It does not invent or define an innovative technology for data exchange, it relies on existing formats, such as IFC STEP and XML and SpreadsheetML (Figure 36), which can be read by multiple customary software, such as Microsoft Excel. It is a standardized way to deliver information and it is an open-source approach to collecting FM usable data. The goal is to organize data developed and collected during the development of a project and to provide facility owners and operators with structured data. (Teicholz, 2018)

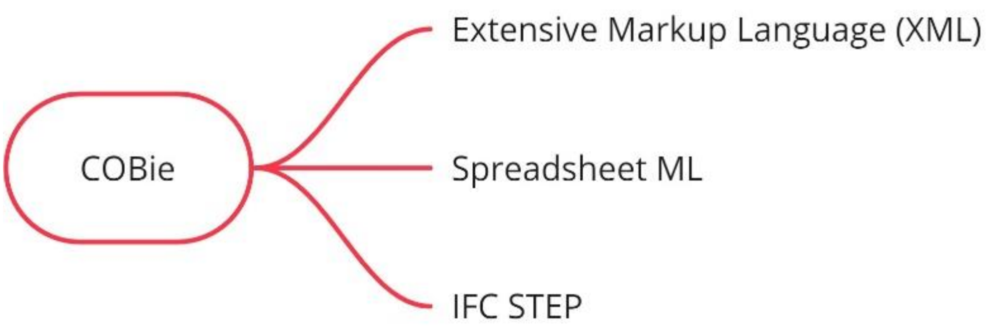

Figure 36 – COBie possible exchange formats – based on Schwabe *et al.*, (2018)

COBie can be summarized as structured information, so a set of specified parameters associated with authoring tools, which use XML, SpreadsheetML or IFC for translation (Schwabe *et al.*, 2018).

COBie is not just a spreadsheet or just a model, as seen before. Also, it is not to be created manually, the aim is to be exported from the authoring software. It is not a process, a product, or even a BIM requirement unless clearly stated in the project's BEP. Lastly, it is also not a naming convention, nor a standard, although it can be part of it. It is mostly a data format that outlines the setup for listing information; however, it does not describe the configuration for information on a specific piece of equipment. COBie is expected to contain information about managed assets i.e., assets that involve upkeep and operating, which require regular ongoing maintenance.

4.4. COBie Roles and Responsibilities

Setting information variables determines "information value" in terms of applicability rather than financial value. According to Wijekoon *et al.* (2017) primary attention should be given to five information variables – "What", When", "Why" "Who" and "How", being the type, the timing, the uses and functions, the users and providers, and the flows of information, guaranteeing the documentation of processes. This information variables can be related to the building process, as it is illustrated in Figure 37. This image's goal is to be exemplificative of different types, uses, providers and flows that can be found during the different Design stages. It constitutes a proposal for responsibilities and data drops within the presented stages according to LIMSEN's experience and workflows.

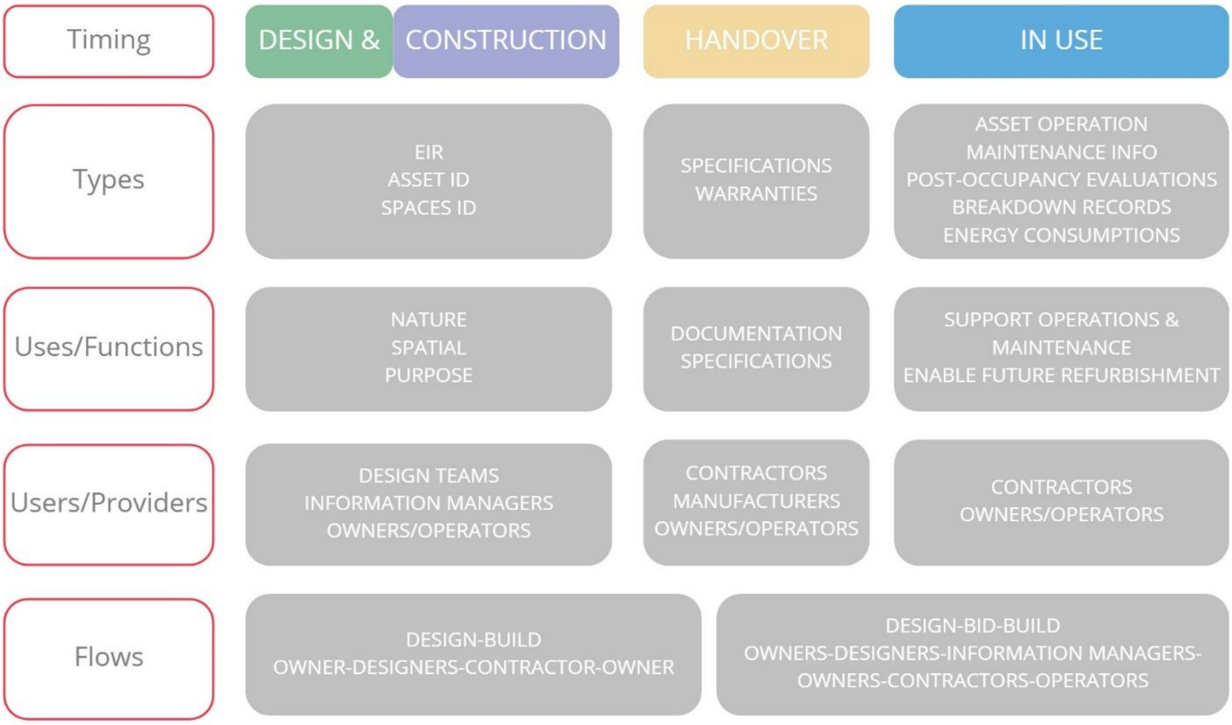

Figure 37 – Information variables related to Design stages

It is relevant to mention that all the illustrated above should be pre-agreed on the Building Execution Plan (BEP) and adapted to the local project needs. In Portugal, for example, it is common that in Design–Bid–Build processes, after the contractor inputs, the Design teams close the drawings for handover. This constitutes not such a lean process regarding the information flow.

To be able to accomplish their goals, facility managers need information from numerous fields and specialties. One major question FM practices assisted by BIM is to define concrete data requirements and to detect the responsible parties and corresponding data drops to be deployed throughout the project life cycle. Historically, scattered information systems have been used to store FM data and information. without a clear assignment of roles and responsibilities within the organization. (Patacas *et al.* 2014)

4.5. Demystifying COBie

4.5.1. Spreadsheet Structure

COBie has been seen as a jigsaw puzzle by many involved parts of AECO/O. East *et al.* (2021) states that even when the information is known in advance, teams still wait until the end of the project to update the information. The absence of data is a result of stakeholders' and technologies' inability to properly document, test, deliver, and use this information. This section aims to contribute to a better understanding of this data transmittal method, as well as to provide AECO/O players with a comprehensive guide on how to deliver and deploy COBie in their projects, making it a useful tool for the industry.

The COBie spreadsheet consists of nineteen default sheets in total. Sheets one through eight of the COBie spreadsheet are normally generated by the authoring software, whereas sheets nine through nineteen are often generated by the O&M/FM software. The nineteen sheets – Contact, Facility, Floor, Space, Zone, Type, Component, System, Assembly Connection, Spare, Resource, Job, Impact, Document, Attribute, Coordinate, Issue and Pick Lists. are listed in Figure 38. Despite Contacts, the first eight develop hierarchical relations between them.

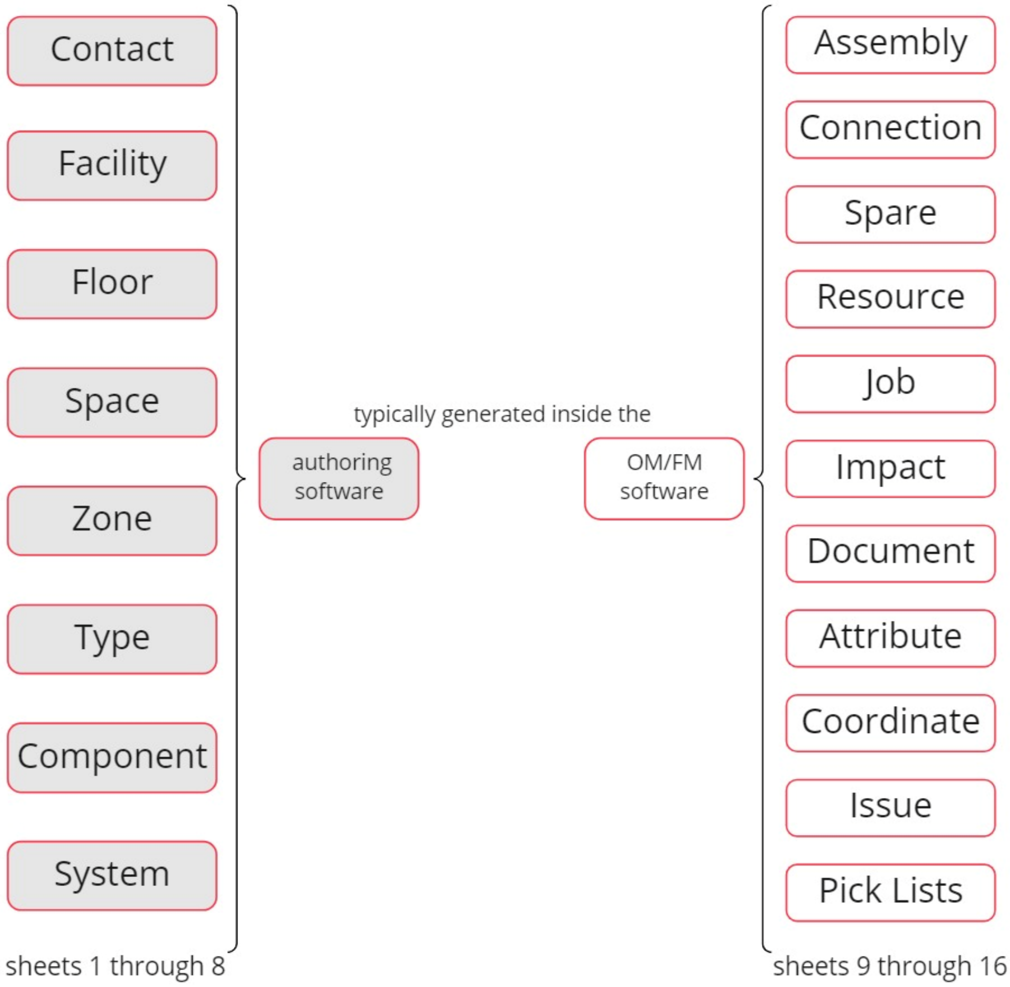

Figure 38 – COBie Spreadsheets Explained

4.5.2. Spreadsheet Interactions and Hierarchies

Sheets relate to one another hierarchically and can be grouped primarily into three categories: first being common elements, second spatial, and third equipment. Common elements include those that apply to both spatial and equipment level elements and are shared by all work stages - Figure 39. They do not have a set hierarchy because they develop as the work progresses. For instance, during the Design stage, relevant Contacts can be only the Architects, Engineers, Information Managers and Owners, while when moving to the Construction phase is also relevant to add the Contractor, main Suppliers and Manufacturers.

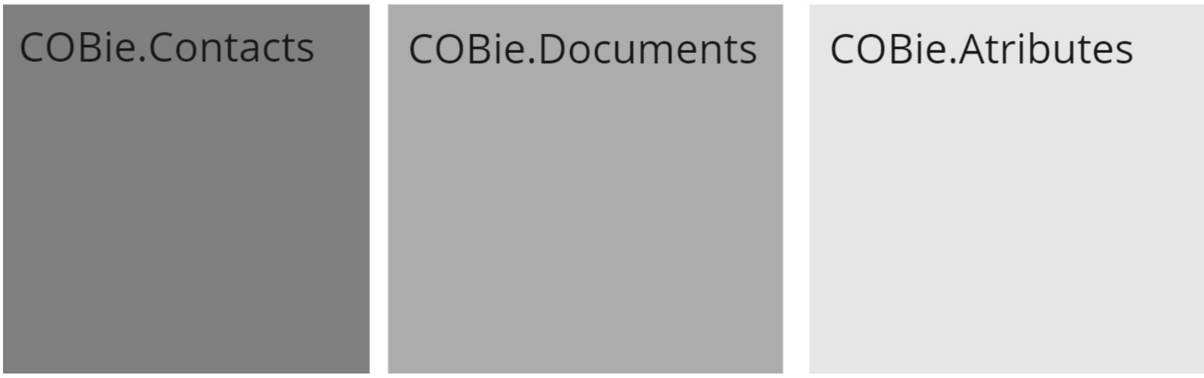

Figure 39 – Common Sheets

Figure 40 illustrates the Spatial level, in terms of how a facility can contain multiple floors and spaces, and a floor can contain multiple spaces. Zones, on the other hand, are simultaneously independent of this hierarchy, but part of this relationship as one zone can contain different facilities, floors, and spaces. The following are specific examples of the stated before: Ex.: one building (facility) is composed of multiple floors (or levels) which contain different spaces (rooms/areas). Ex: A zone can be defined by fire rates, so it can surpass multiple floors or spaces.

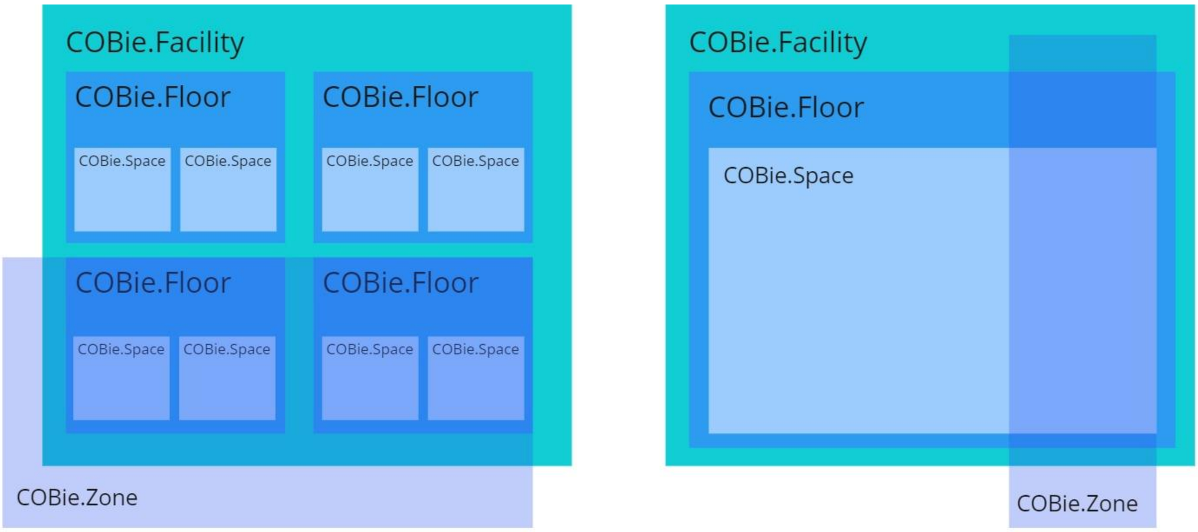

Figure 40 – Spatial Hierarchyand Relations

Regarding the Equipment level, Figure 41 explains the second hierarchy and relationship, as one equipment type can have multiple components. An example of a type would be a HVAC Air Handling Unit which would have multiple components, being filters, fans, motors, belts, cooling/heating batteries and condensate drainers. Systems are also independent but related to them, as one system can contain different types and, consequently, different components. Nevertheless, the same type can be part of different systems. For example, a HVAC system can be composed of Air Handling Units, Water Chiller, Recirculating Pumps, Water Tank, Fan coil Units (multiple types) and the same Fan Coil Unit can be part of two different systems.

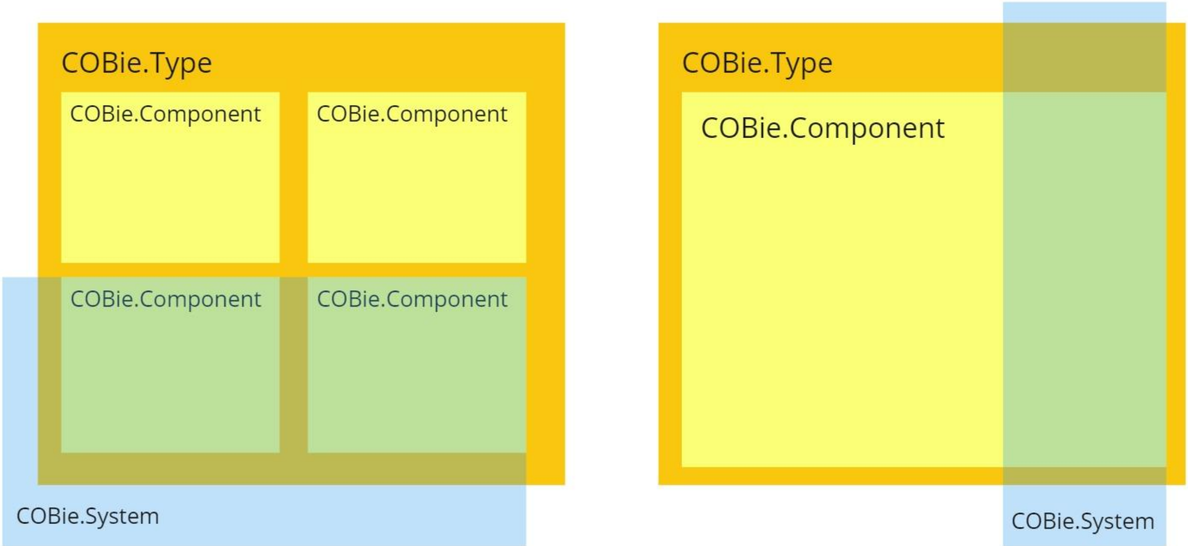

Figure 41 – Equipment Hierarchy and Relations

Figure 46 illustrates how hierarchies can also be related to work stages. When considering a project examples the Design stage, is where all the spatial properties start to be defined. The Facility is managed through Zones and Systems. Zones contain one or more Spaces and Floors. Floors contain Spaces, which contain Components. When in the Construction stage, all the definitions of the equipment need to be settled already. Each definition is represented by Types.

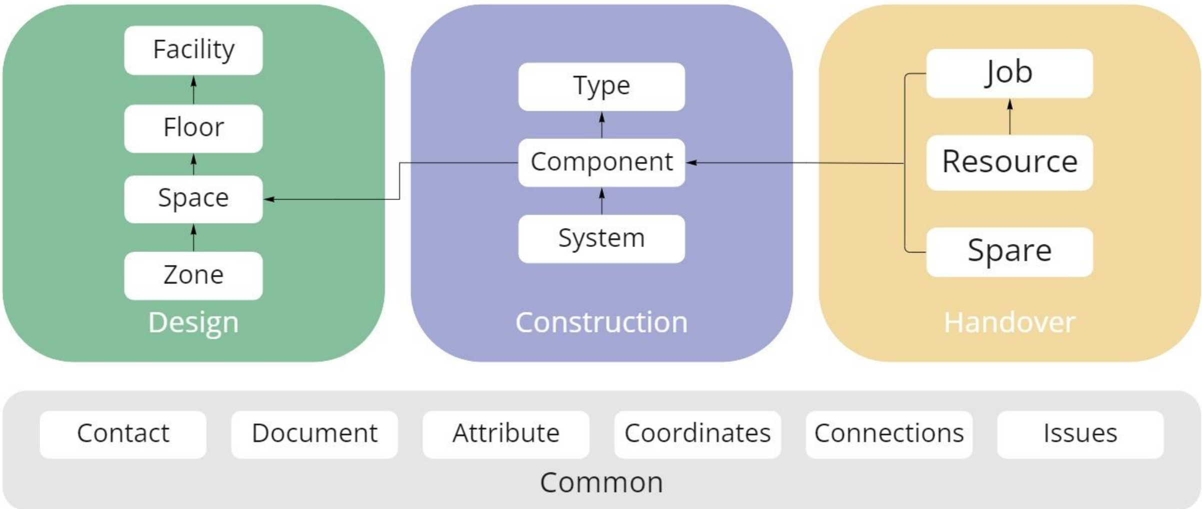

Figure 42 – COBie Interaction Schema based on (East *et al.*, 2021; Teicholz, 2018)

Finally, Handover to In Use stages rely on maintenance tasks, designed as Job. These require Resources and Spares to complete it. The common elements relate to additional information and go through all stages.

4.5.3. Spreadsheet Colours and Requirements by project stage

Each specific COBie sheet consists of a different number of columns that correspond to various data needs. The required data needs (columns) vary in characteristics (colour) depending on the project phase, or information requirements agreed by the involved parties, as illustrated by Figure 43. All the available templates of COBie spreadsheets contain a so-called Instruction spreadsheet where this colour code is explained, as well as basic information and description about the sheet contents are provided.

Colours inside COBie spreadsheet regarding sheets and columns have different meanings, where yellow stands for mandatory information, orange means it is already filles or referenced in another sheet, purple, that it is externally filled by the authoring software, green, that it is filled only upon agreement, and white, that it is not required for the current work stage. Not so common but also possible is to see the blue colour for regional requirements or the grey used when preparing product data. These last two colours are applied by the user, as they correspond to user-defined sheets.

As an illustration, if a column is yellow, it is necessary for the current stage, however if it is white, it is only necessary for the stages that will follow. Columns in green are always optional and should only be filled out if previously agreed. Columns in purple relate to external references are not supposed to be edit manually by the user.

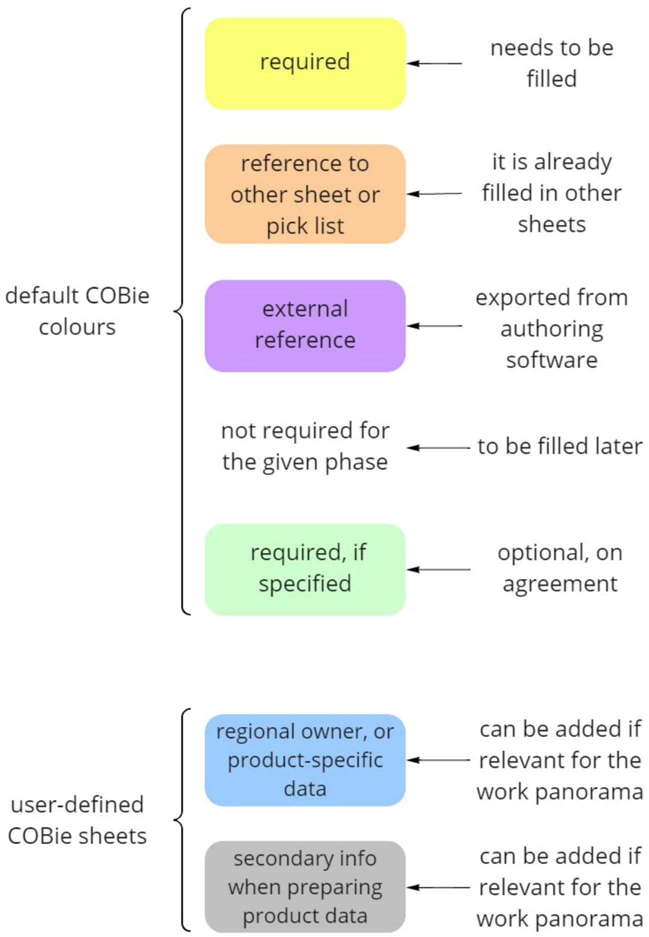

Figure 43 – COBie spreadsheet Colours

When consulting the buildingSmart documentation regarding COBie (buildingSmart, 2022), it refers to the Whole Building Design Group (WBDG) website. The WBDG is an entity that counts with the participation of several American federal entities and agencies, and it provides multiple examples of COBie sample spreadsheet files depending on the project's level and nature (WBDG, 2021). Up to five files examples corresponding to the different work stages under different building uses are available. To assist with the task of determine the COBie requirements at each stage, the WBDG examples were examined and contrasted with LIMSEN's present practice. An office building example was part of the available usages and as it fitted a significant volume of the buildings that LIMSEN's interact with, it was seen as the most suitable example to consider. These files allowed to assess the data organization and to track the progression of COBie data through different work phases.

The major objective was to comprehend how the COBie requirements change as the job progresses, followed by a critical evaluation of its application to the company's reality and result in the development of a similar matrix, although customized to the corporate context of this dissertation. The next three figures – Figure 44, Figure 45 and Figure 46 provide a visual and more intuitive interpretation of COBie spreadsheets, where each column denotes a sheet. All the columns that make up the sheet are listed underneath each of those. These figures can be found in better resolution in the Appendices 3,4, and 5.

As in the previous chapter, RIBA work stages designation was adopted. Design corresponds to the late Technical Design stage, right before the assignment to Construction, which stands for the entire production and assembly of the building. Finally, the Handover stage corresponds to final assessments from the contractor, right before delivering the building to be used, operation and maintenance in the In Use stage.

For the Design template provided by WBDG, represented in Figure 44, ten sheets are designated as required (yellow) being sheets one to eight, Contac, Facility, Floor, Space, Zone, Type, Component and Space. Designation (Name) and the date of creation (CreatedOn) are required for all of them. Categories, Type Names and Components are referenced to other sheets because are usually filled in inside the authoring software.

When compared to the previous stage, the COBie spreadsheet for Construction includes three extra sheets: Spare, Resource, and Job. This data relates to maintenance tasks and predicts the information requirements for the subsequent stage. Additionally, details about models, manufacturers and warranties must be included under Type and Component. Multiple elements under Type are still optional under agreement.

The same mandatory sheets are included for Handover/In Use stages, but it specifies what information belongs in the Assembly, Connection, Coordinates, and Issue sections. According to the WBDG, these sheets are never required at any time; nevertheless, if the user chooses to supply this information, the requirements are stated in the Handover template. Designation (Name) and date (CreatedOn) are marked as mandatory for all of them; then Job.Description, Duration and Frequency; Document.Directory and File; Attribute.Value and Unit; Coordinate.XYZAxis and Rotations and Issue.Description and Mitigation. Also, in both the Construction and Hando ver stages, the Impact Sheet is designated as optional by agreement.

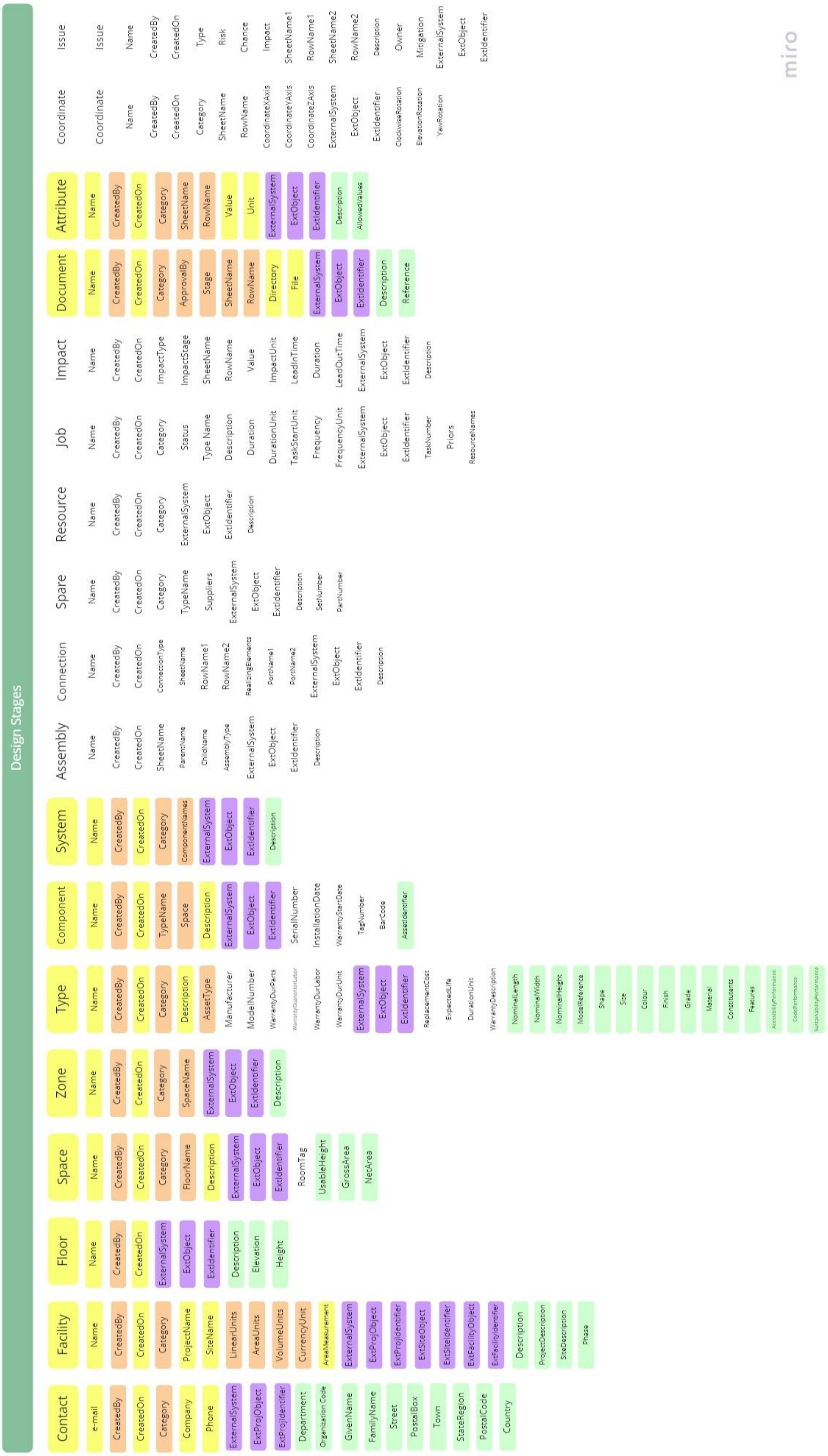

Figure 44 – COBie Spreadsheet requirements for Design Stage

Figure 45 – COBie Spreadsheet requirements for Construction Stage

Figure 46 – COBie Spreadsheet requirements for In Use Stage

4.6. COBie Planner

4.6.1. Planner Levels – Lite, Intermediate Full

After comparing the required information from the available examples and considering the company's professional experience working with various teams, it was clear that these requirements were too stringent for teams who were yet unfamiliar with the mission of providing valid COBie deliverables.

According to LIMSEN's experience, some resistance to the delivery of COBie data is still encountered, both from Design teams and the contractor, mostly due to the factors explained earlier, such as a lack of global understanding of the process and the desired information requirements for each phase. COBie Planner stands as the materialization of the described framework, based on COBie and allowing to plan the information to be delivered. The COBie Planner was intended to be a straightforward and self-explanatory tool that would enable the accomplishment of this specific goal.

In order to accommodate the project's stage of development and the needs of different owners, it was agreed that it would make sense to display three degrees of information granularity, as shown in Figure 53. Starting with Lite in the Design Stages, guaranteeing that basic information is filled, to work as a foundation for upcoming Construction – Intermediate Level, and finally Full, on the Handover stage.

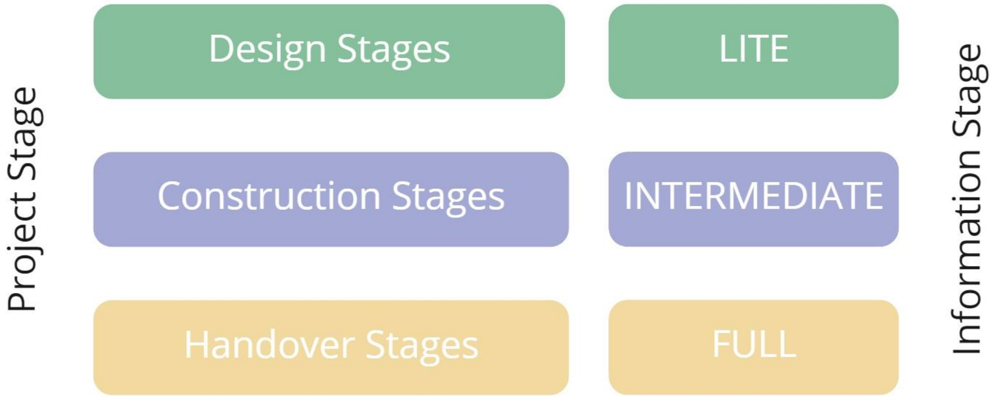

Figure 47 – COBie Planner Levels

The content of each level is listed in Figure 48 and explained with detail in Figure 49 and Figure 50.Those can be found in better resolution in Appendices 6 and 7. For the Lite level, only five sheets are required, regarding basic data: Contact, Facility, Floor, Space and Zone. According to what was established in Figure 37, this is a responsibility of Design teams, which require third parties assistance, as from Information Managers. These five sheets are connected to the first hierarchy presented in Figure 40 and to the Common Sheets in Figure 39. The Intermediate level contains all the information present in the previous one, plus the Component and Type information. This can be assigned to Design teams in the late stages of Design or to the Contractor, depending on what was decided in the Building Execution Plan (BEP). Full is the most complete, where despite all the previous information, two more common sheets were added – Document and Attribute, and Systems – the more complex represented in Figure 41. According to LIMSEN's professional context and experience, it did not make sense to include all sheets at the full level as it would be too complex for the work teams. It was therefore decided to add a "Customized" level, where, if agreed with the client, all information could be included, even that which already refers to elements of the operation/facility management phase – such as Job, Resource and Spare. According to East *et al.* (2021) Connection sheet has not been widely used and it is expected to be depreciated soon, so it was not included in the Planner. Coordinate and Issue were not included either, as they mostly relate to specifically locate and describe handover issues.

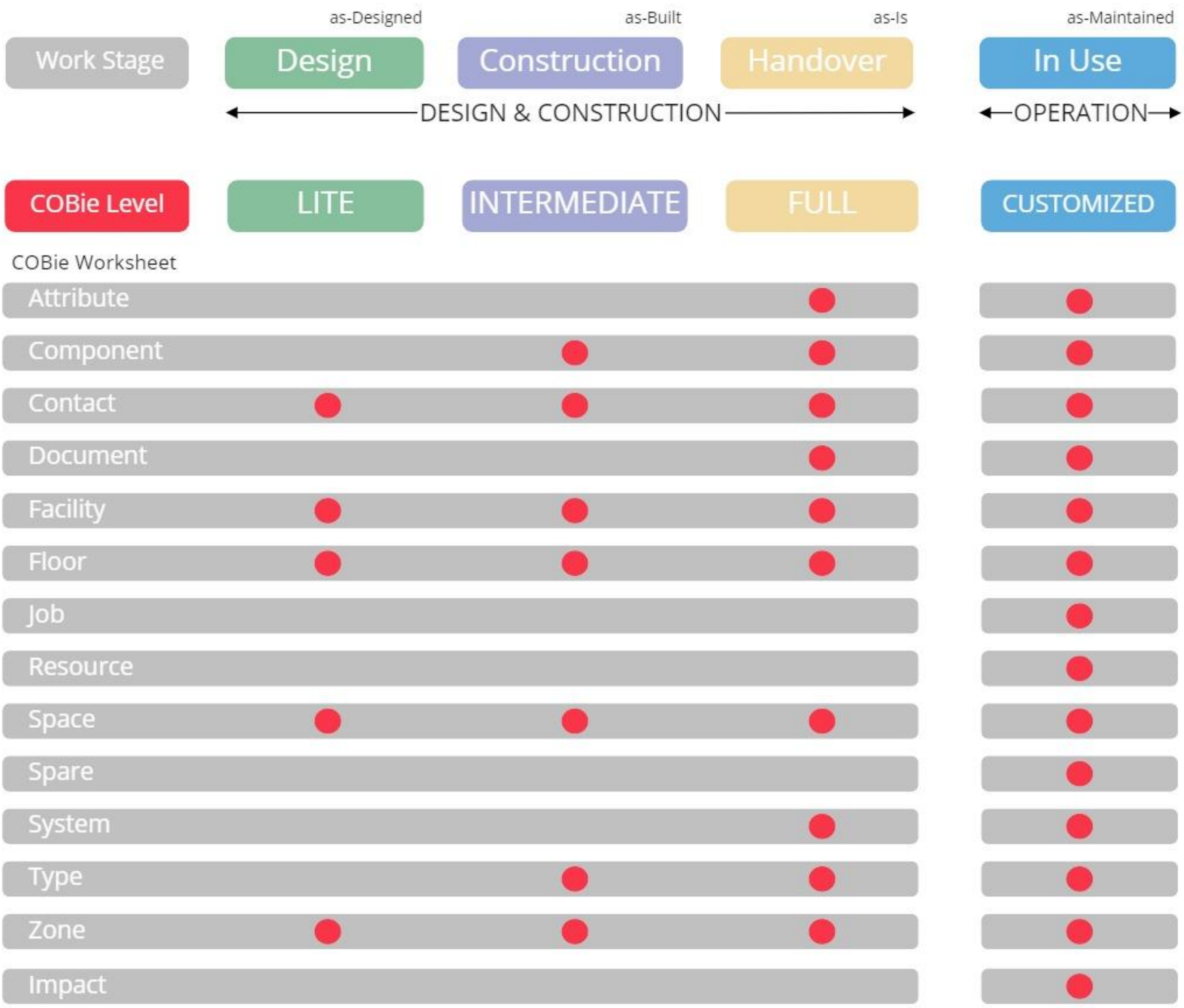

Figure 48 – COBie Planner Data Drops

After defining which sheet would be part of each level, a global planning was established, as illustrated by Figure 48. It exemplifies the data to be found in each sheet, according to the different levels of granularity. The “required, if specified” (green) fields of each sheet were not considered at any stage, as they constitute additional information that can be added anytime.

In the Lite level, it was necessary to have Contact, Facility, Floor, Space, and Zone because the objective was to start with fundamental information about spatial hierarchies. The Intermediate level, which focuses on equipment, added three sheets—Document, Type, and Component (Figure 49). Attribute and System were included in the Full stage, which is depicted by Figure 50, as all the information is expected to be known by the teams at this point. Adding a customized level made sense so that, at the clients' request, particular data for operations and maintenance could be provided.

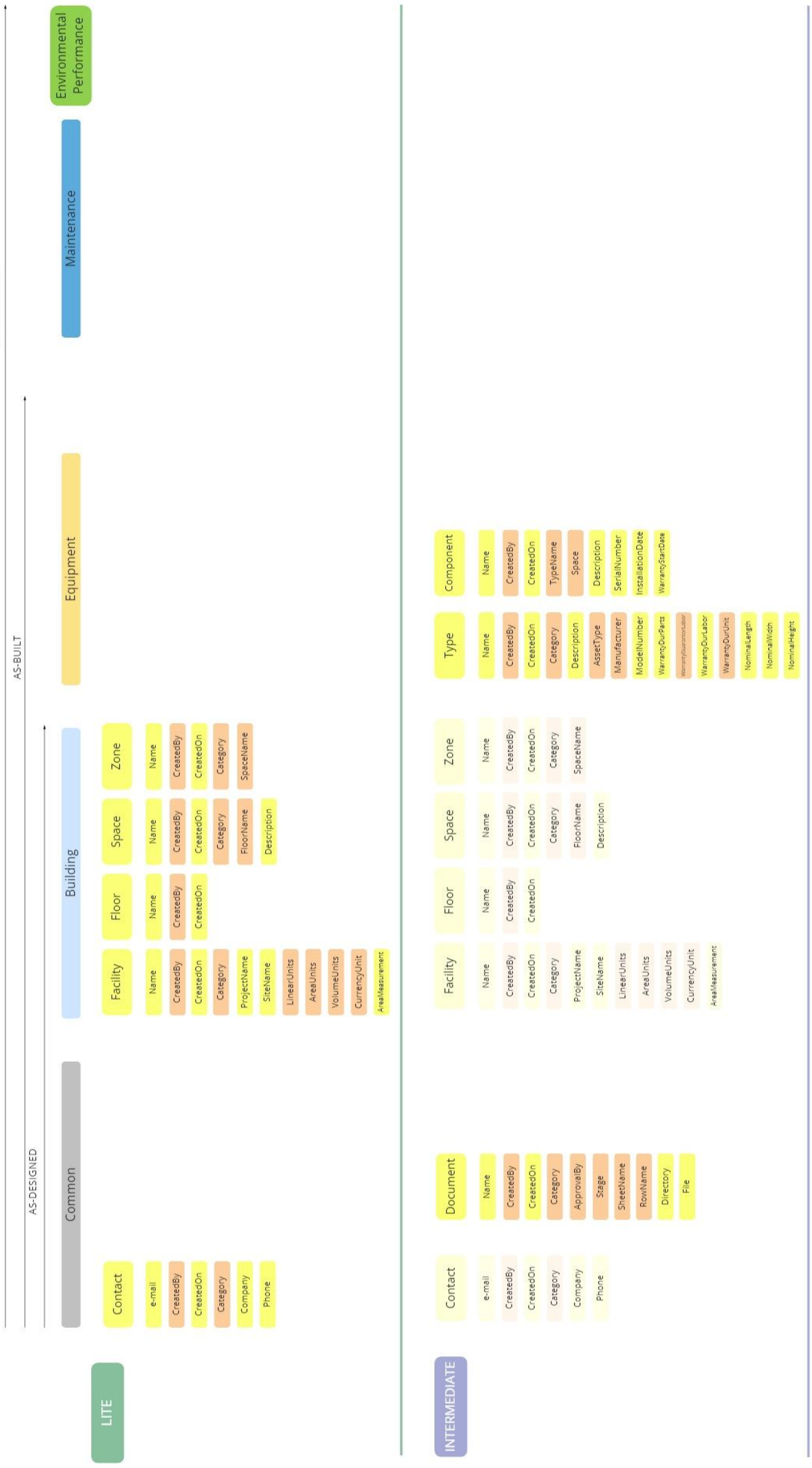

Figure 49 – COBie Planner Lite and Intermediate

Figure 50 – COBie Planner Full and Customized

5. CASE STUDY RESULTS AND DISCUSSION

The presented case study consists of three main phases: the creation procedure, on the Planerly platform, the assessment procedure in the authoring software Revit, and the validation by assessing the integration into O&M / FM software Dalux – Figure 51. The main goal was to support information managers to provide teams with concise information requirements along with clear roles and responsibilities, while filling the information in the authoring software assisted by COBie Planner. The last stage will ensure that the information produced in early work stages was valid for O&M/ FM.

An ongoing project from the partner company LIMSEN was used as a placeholder for the information. Of all the projects that the company has in progress, this one was selected since it was important to test the information flow from the Design to the Construction phase. As the main goal was to check the information interoperability and usability through all the work stages – project information lifecycle – it was not considered of major relevance to describe or elaborate on the architectural and formal characteristics of the building. The selection of the described procedures also had into consideration the practices of the company and others involved in the project, being Planerly and Revit already used daily, while the contractor was using Dalux on the construction site.

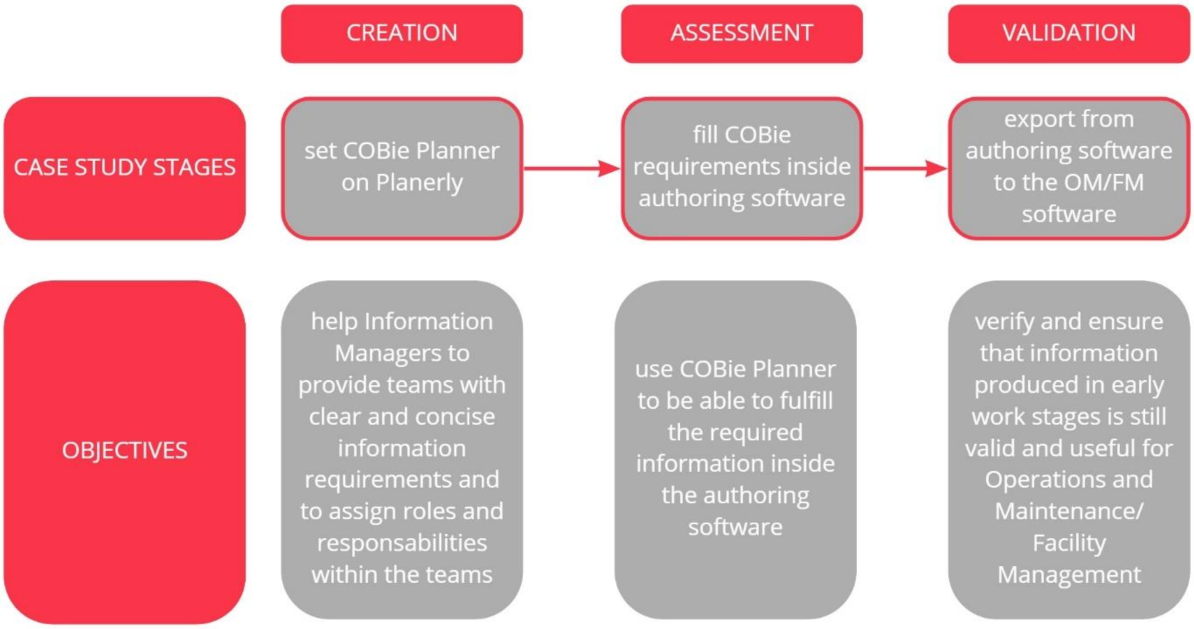

Figure 51 – Case study development process

5.1. COBie Planner integration with Planerly platform

As mentioned earlier in Chapter 4, it is considered that the existence of a structured document regarding COBie, explaining what it is and how to make effective use of this tool is of added value for a company providing BIM information management services. This allows the company to provide this knowledge to the teams involved from the outset, ensuring that they have all the necessary background information to deliver what is required of them. LIMSEN's workflow includes the definition of the BEP using the Plannerly platform. This web–based platform allows the construction of documents from pre-defined templates and imported documents from word and/or excel. It was logical for the company's actual situation that this information be loaded into the BEP, so a chapter entitled COBie was included in LIMSEN's BEP template in Plannerly, which integrates the results of the research of this dissertation, as well as a detailed explanation of the COBie Planner and its operation. A default project was created and entitled COBie Planner (Figure 52), and default teams were added to allow the assignment in the Scope tab – Figure 53. The developed template used the Plan and Scope tabs and allows further use of Verify section if connected to Autodesk Construction Cloud (ACC).

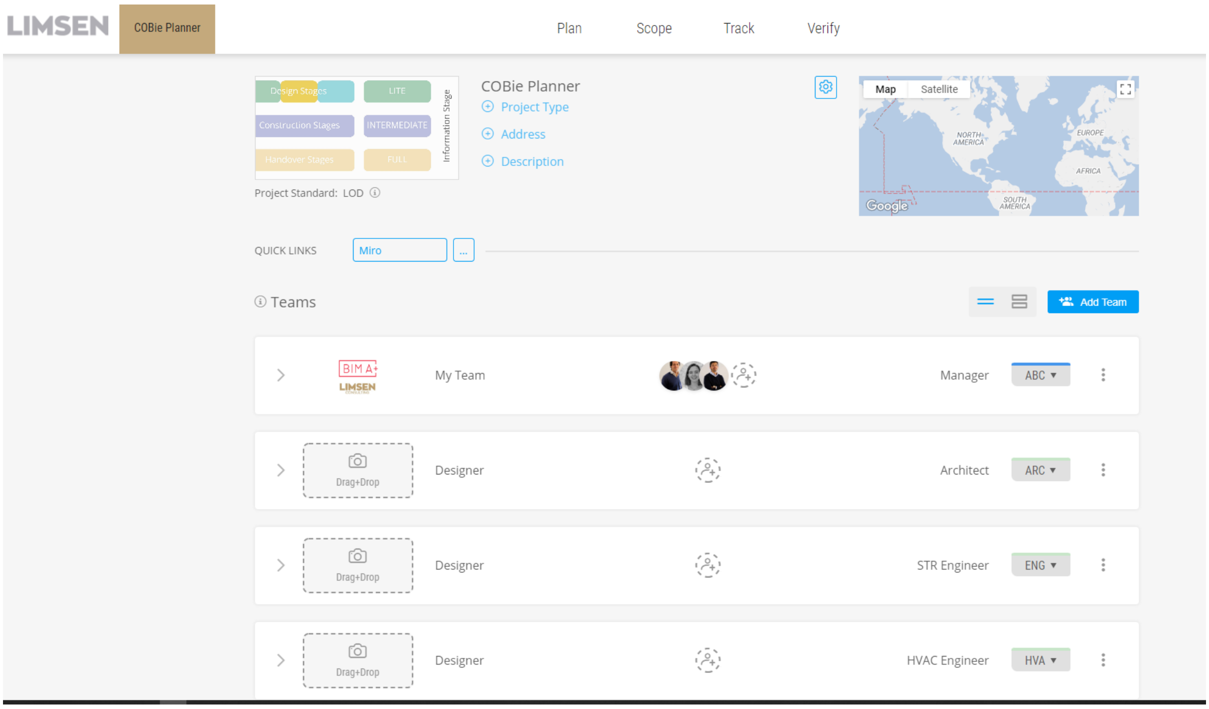

Figure 52 – Planerly front page

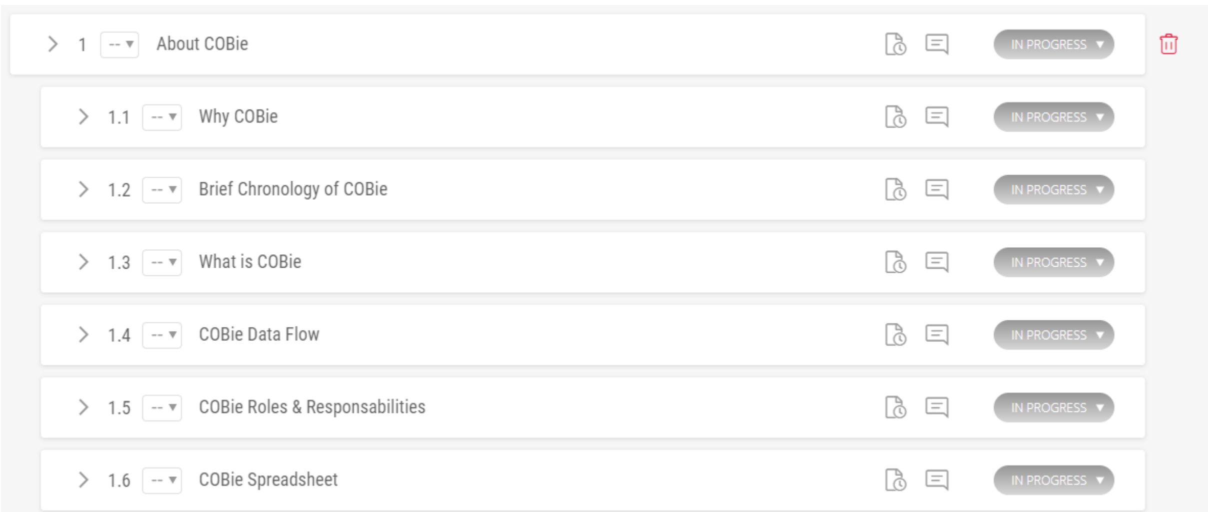

Figure 53 – Planerly Sections – part 1

In the Plan section, two main sections can be found, both based on the contents presented in Chapter 4 of this dissertation. The first section provides an explanation about why using COBie, followed by a brief chronology of this tool, what it is, its data flows, and roles and responsibilities. The last sub-chapter of section one (1.6.4) goes deeper into the spreadsheet itself, explaining its referencing colours, content structure and the requirements by project stage according to the WBDG – Figure 54.

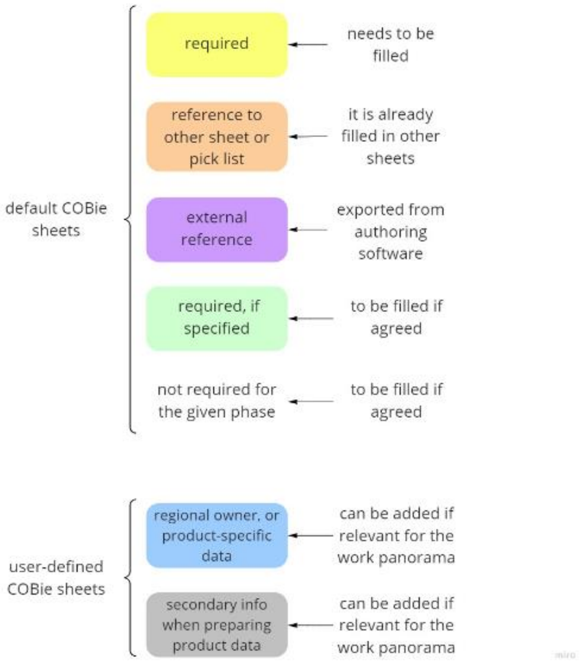

Figure 54 – Planerly Sections – part 1– example of COBie colours explained

The second section focus on the user-guide of the COBie Planner – Figure 55, detailing the levels, the sheets relations, and the information requirements –Figure 56.

Figure 55 – Planerly Sections – part 2

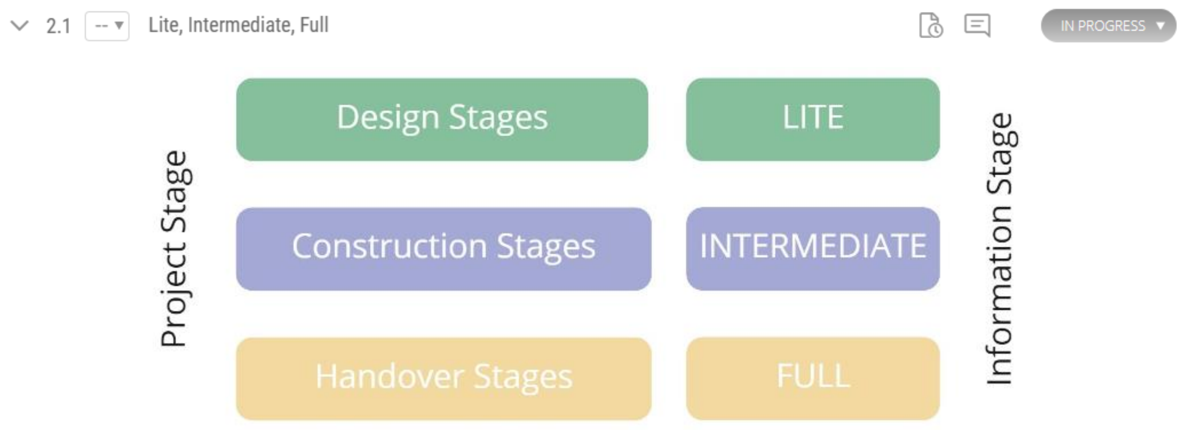

Figure 56 – Planerly Sections – part 2– example of COBie LEvels

A table per COBie sheet defined in the COBie Planner with examples of the requirements was created inside Plannerly to support the work of the teams when filling in the information, by relating the COBie property with the description and examples – Table 3 and Table 4. Space and Type tables are shown in this section, while the remaining (Contact, Facility, Floors, Zone, Component and System) can be found in Appendix 9. These tables main goal is to be a practical tool to be consulted at any stage of the work.

Table 3 –Space Information Requirements

COBie	Description	Example
Name	Room Number	001
Category	Classification Code: Classification Title	13-25 13 13 : Entry Lobby
FloorName	automatically mapped from Revit Level Name	T3_L0
Description	Room Name	Hall/Reception
External Fields	automatically filled by Revit	
RoomTag	Concat Room Number_Room Name	001_Hall/Reception
NetArea	Area, no units	143

Table 4 –Type Information Requirements

COBie	Description	Example
Name	Tag - Type parameter - TypeMark, Assembly Code, Keynote, Shared Parameter	FCU
CreatedBy	Choose from the created Contacts	Email
CreatedOn	Date	YYYY-MM-DD
Category	Classification Code : Classification Title	21-04 30 30 10: Central Cooling
Description	Type Name or Type Description	Fan Coil Unit
AssetType	Choose from 2 values: Fixed or Moveable	Fixed
Manufacturer	Designation	Daikin
ModelNumber	Designation	
WarrantyGuarantorParts	email, contact	commercial@daikin.com
WarrantyDurationParts	numeric	3FXSQ-A
WarrantyDurationLabor	responsible entity contact, email, website	commercial@daikin.com
WarrantyDurationLabor	responsible entity contact, email, website	commercial@daikin.com
WarrantyDurationUnit	time description (year, month, week)	year
External Fields	automatically filled by Revit	
DurationUnits	time description (year, month, week)	year
Nominal Dimensions	meters	0.90
ModelReference	product commercial designation	FXSQ-A
Shape	solids	rectangular
Colour	text	grey
Finish	text	stained
Material	text	stainless steel
Constitutents	parts that need maintenance, text	filters
Features	product URL	https://www.daikin.pt/pt_pt/products/fxsq-a.html

In the "Scope" tab, illustrated by Figure 57 the requirements regarding the elements can be found. Initially, the Uniformat classification system was used, as it is the one the company is using. However, during the process, it was realised that Omniclass would be more inclusive, as the Uniformat does not comprise spaces/zones. Therefore, tables 13 and 21 of the Omniclass system were integrated into Planerly.

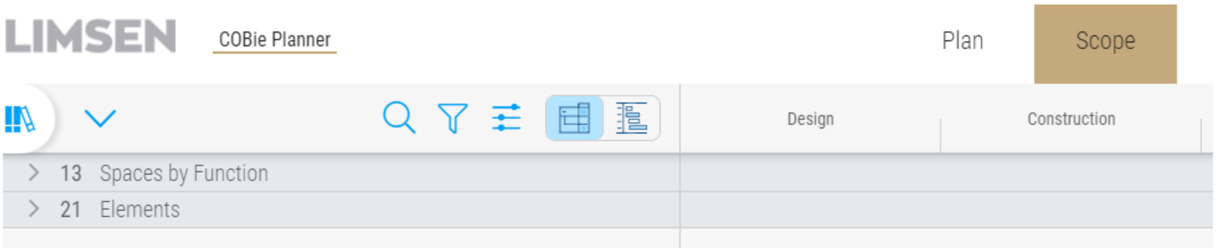

Figure 57 – Planerly Sections – part 2

The COBie levels were integrated into the Information section as Project Information Requirements – Figure 58. With this, it is possible to go back to "Scope" and assign Tags to the Elements, which can later be checked in the Verify tab.

Figure 58 – COBie Levels integrated into Planerly

Also, individual Tags were created regarding COBie sheets and assigned to the correspondent Levels – Figure 59. In this figure, the "Applied To" column indicates zero, as these Tags were still not applied to any elements. The verification rule was a simple "Text contains" "COBie", that can be adapted to each project.

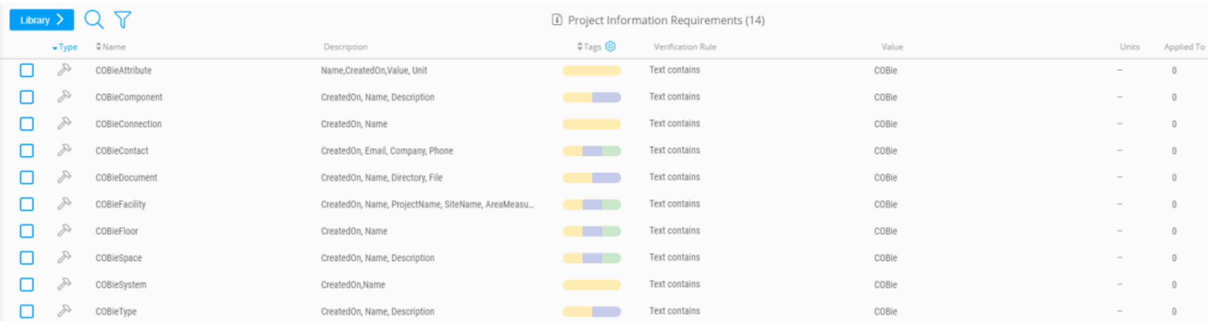

Figure 59 – COBie Sheets integrated into Planerly as Information Requirements

This strategy allows the user to filter, in case of doubt, what are the items present on each level. In the "Tags" tab, the colours indicate at which levels that information is required – Figure 61, Figure 62.

The "Description" column enumerates which information should be present on each sheet. As it can be seen in Figure 62, as the filter is changed to "COBieIntermediate", more items are added to the list. After filtering, it is also possible to sort the elements by Tag, so the user knows if the required information is part of other levels. COBie.Type, for example, should be part of Intermediate and Full, while COBie.Contact is required at all levels.

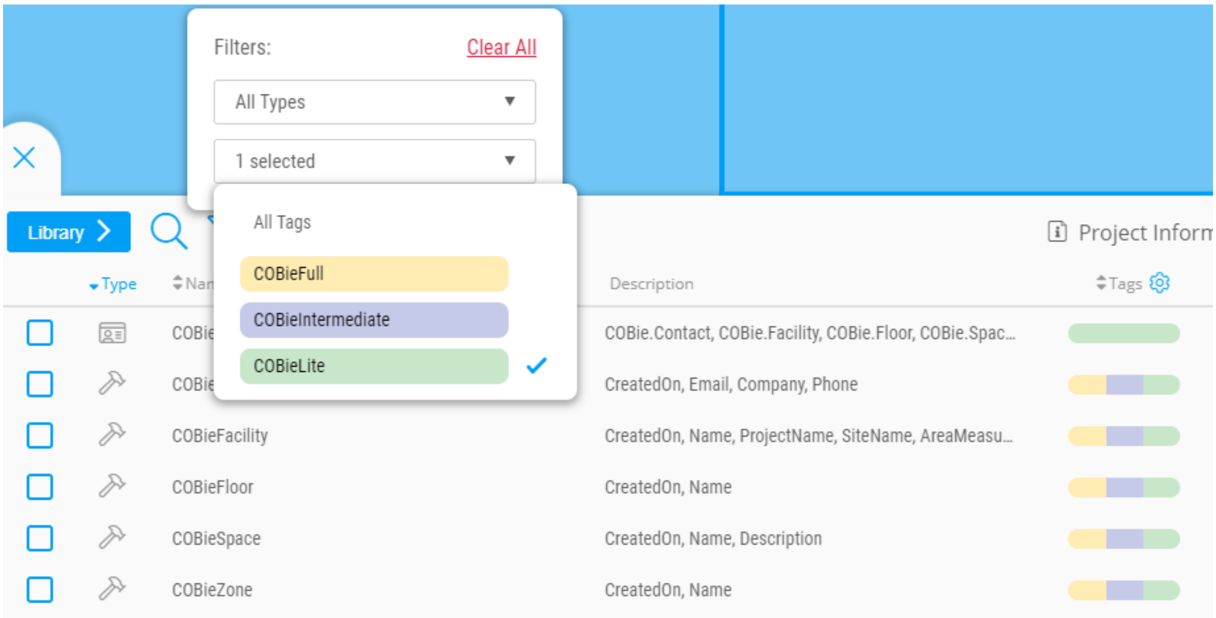

Figure 60 – COBie Sheets filtered by “Lite” Level

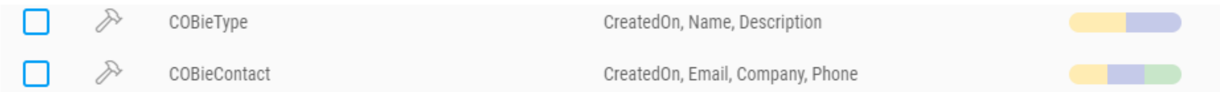

Figure 61 – COBie Sheets comparison regarding Tags

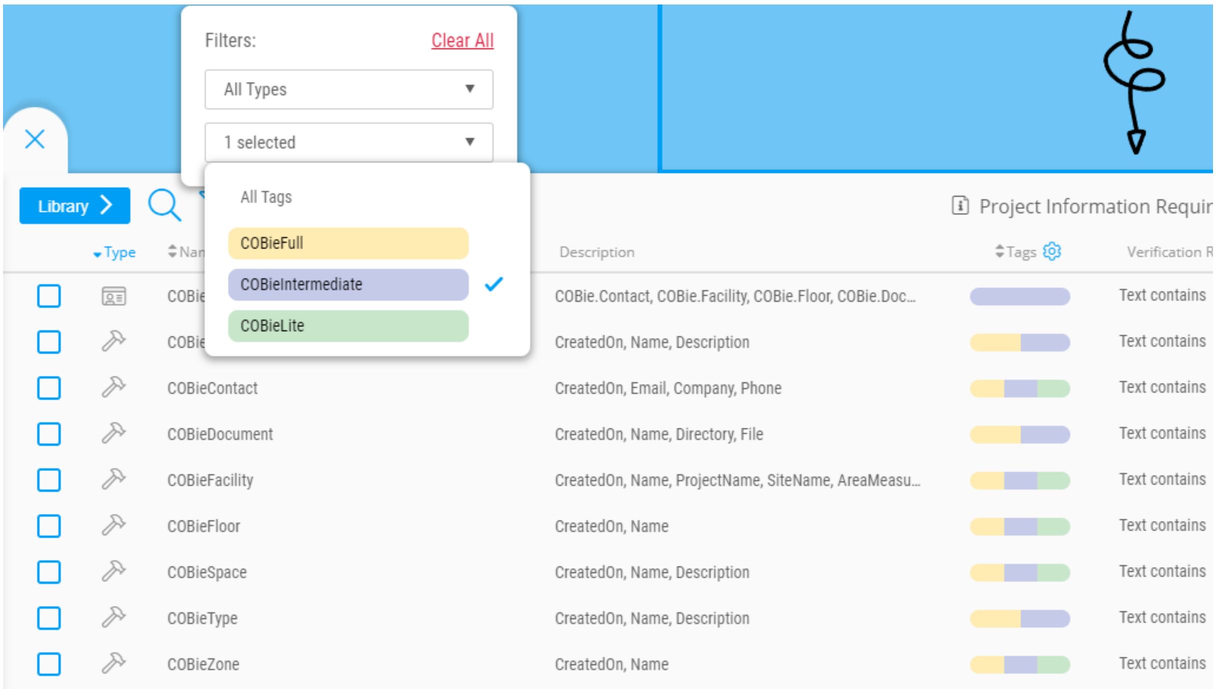

Figure 62 – COBie Sheets filtered by “Intermediate” Level

After the Tag creation, it is possible to assign the Information Requirements to the elements. When those are assigned, a small icon of a sheet with an “I” appears on the down left corner. Assigning all the information requirements (one for each COBie Sheet that should be included in that stage) in all BEP elements, would be very time-consuming to the Information Managers and quite confusing to the user, especially for beginners. The proposed method is to have Lite, Intermediate or Full checked according to the work stage of the project. If the user is not sure about the content of each level, can either consult the Plan section or apply the same method as described above, by going to the information requirements and activating the filter for the desired level, which will show the correspondent properties to be considered. The three categories selected to be used as examples throughout this chapter –Figure 63,Figure 64,Figure 65 – sought to be transversal to work stages (Spaces), as well as encompass different disciplines and thus providing a broader scope for the reader.

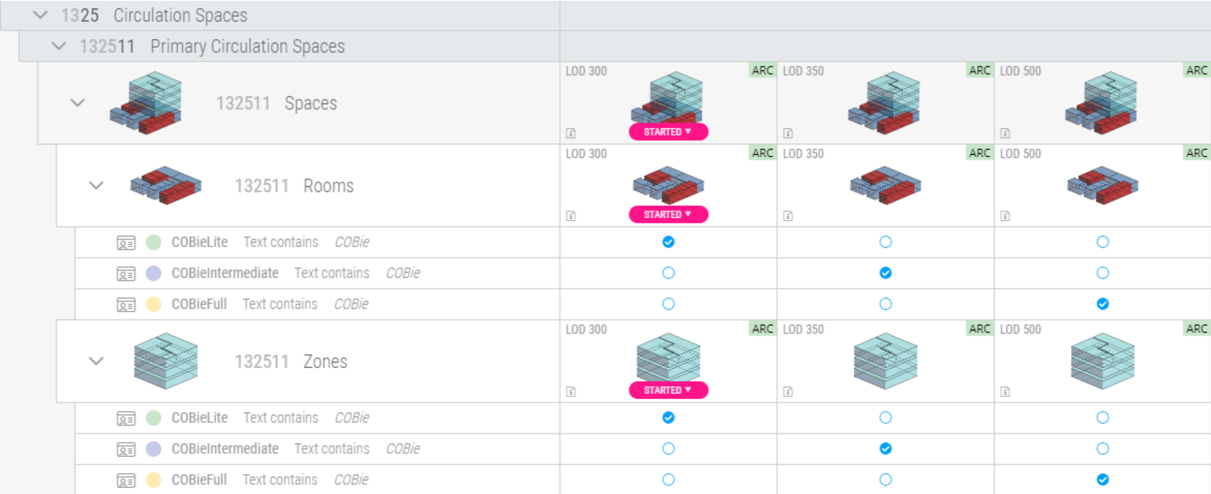

Figure 63 – Information Requirements applied to Spaces

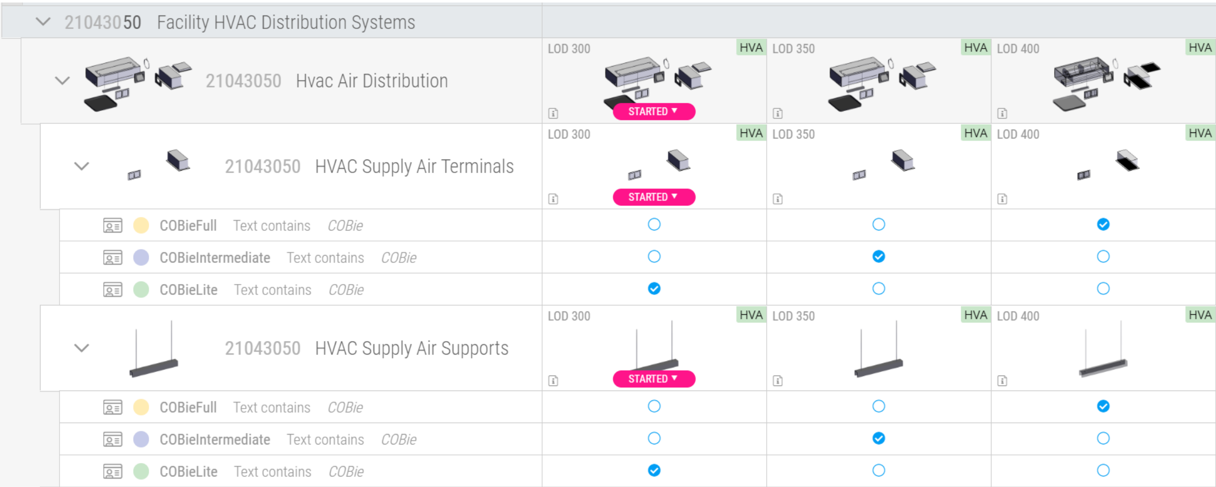

Figure 64 – Indication of Information Requirements applied to HVAC

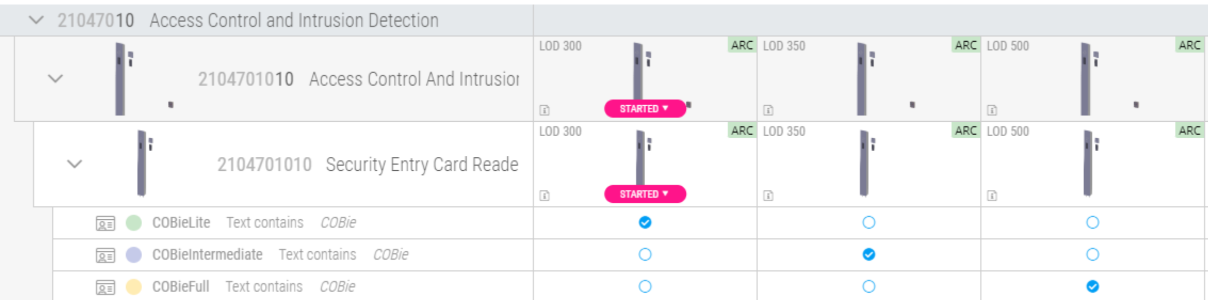

Figure 65 – Indication of Information Requirements applied to the Turnstile

By clicking on each LOD, detailed information is provided, as exemplified by Figure 66, it is visible how many elements these requirements are applied to and if the cursor passes by, a window appears with the description. In the example of Figure 66, HVAC Air distribution is composed of eight elements, that have inherited these requirements.

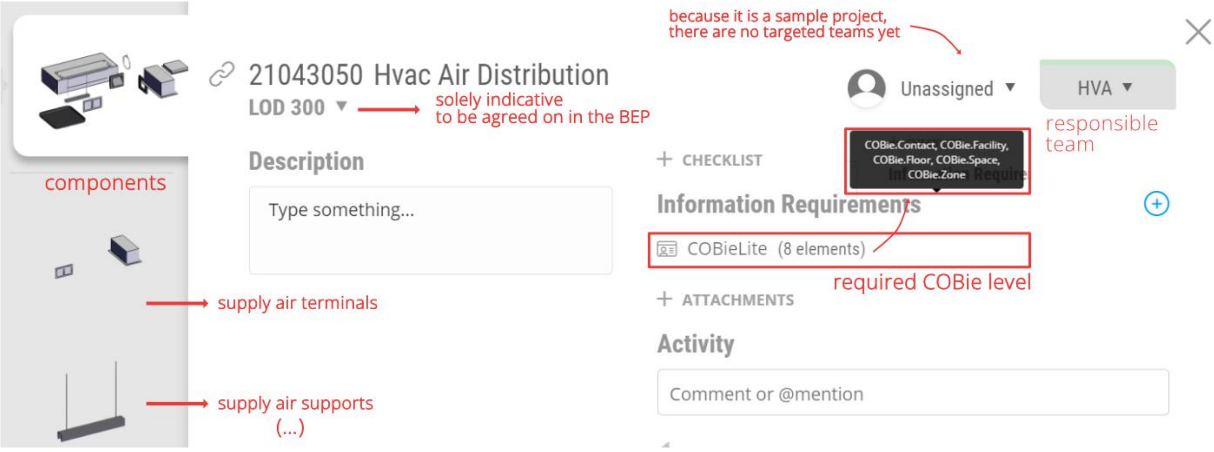

Figure 66 – COBie Information Requirements applied to Facility HVAC

In addition to improving communication with the teams, who can thus search for the COBie information in the same place where they already searched for general BEP aspects, the introduction of these information requirements in the "Scope" tab will allow further verification, in the "Verify" tab, which is connected to Autodesk Cloud Collection. This will simplify the Information Managers' workflow when checking the model's data compliance.

5.2. COBie Planner in use inside authoring software

The chosen software was Revit, as it was already being used by the partner company and it was also available under an educational license. To enable COBie parameters in the model objects, BIM Interoperability Tools tab needs to be initialized. The extended configuration used for this dissertation can be consulted in Appendix 8a to 8m. As a brief description of the proposed workflow, represented by Figure 67First, contacts should be settled, as they will appear in all the COBie sheets, being used by the "Created.By" field. Second, the "Setup Project" will allow the user to define general matters and all the definitions regarding Spaces, Type, Components, Systems, Attributes, Coordinates and Parameter Zones need to be assigned manually by dragging the spaces, as HVAC zones are different elements.

Figure 67 – COBie menu inside Revit

Six categories are available from a pre-defined in a drop-down menu being Circulation, Fire Alarm, Historical Preservation, Lightning, Occupancy and Ventilation.

Finally, update will parse the information in the elements and then it is possible to generate the spreadsheet. Another option is to import pre-defined mapped parameters or export the current setup for later retrieving. When creating the spreadsheet, the following window (Figure 68) appears. Here, COBie Planner can be of use, when thinking about which sheets are needed for the export. The dots in Figure 68 relate to COBie Planner defined colours.

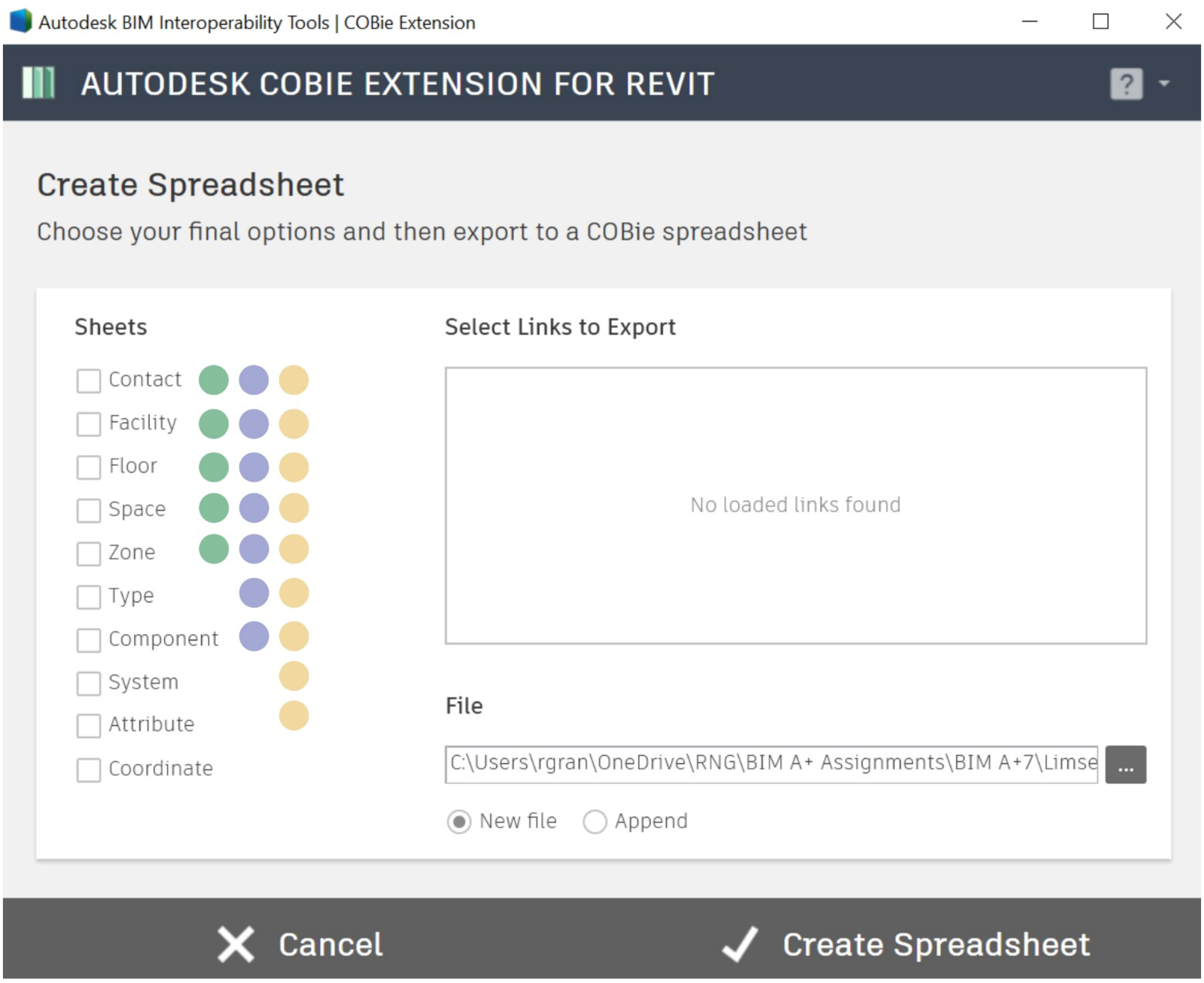

Figure 68 – COBie spreadsheet creation through Revit

Spaces inside Revit only allow information by instance, as they don't contain types. Figure 69 shows what would be the necessary information to fulfil regarding spaces through all the proposed COBie Levels. The dashed box around COBie.Space. Room. Tag means that filling this field is optional in this stage, however, the designer did it in advance. The last three attributes are only to be filled if agreed, and for the client, it was useful to have all the room's height, gross and net area, so the values are already indicated as well.

The colour code is the same used in the previous sections, the green box surrounds the needed attributes for the "Lite" level, the purple is for "Intermediate", and the light yellow "Full". The dashed black is for optional fields, which in this case were considered not relevant so they don't show any value. The light green indicates the "required if specified" field, and it was filled on the agreed fields to be relevant to the project scope.

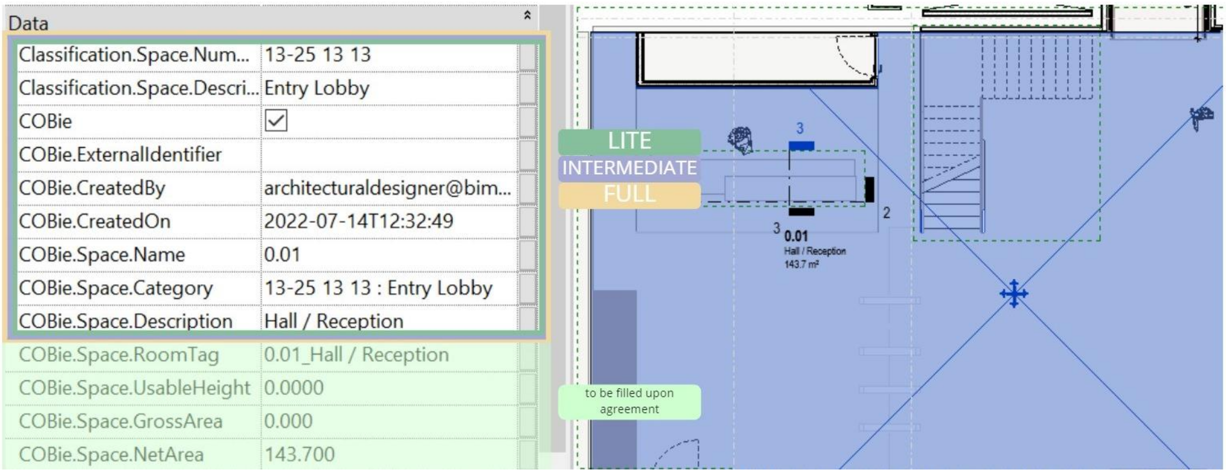

Figure 69 – COBie attributes filled inside Revit – Space example

Another example is a turnstile, which is placed in the previous space. It represents a broader example, as it contains both properties by type and instance (several instances of the same type can be placed in the project). Again, the rectangles indicate which fields are required in each COBie Level (Figure 70).

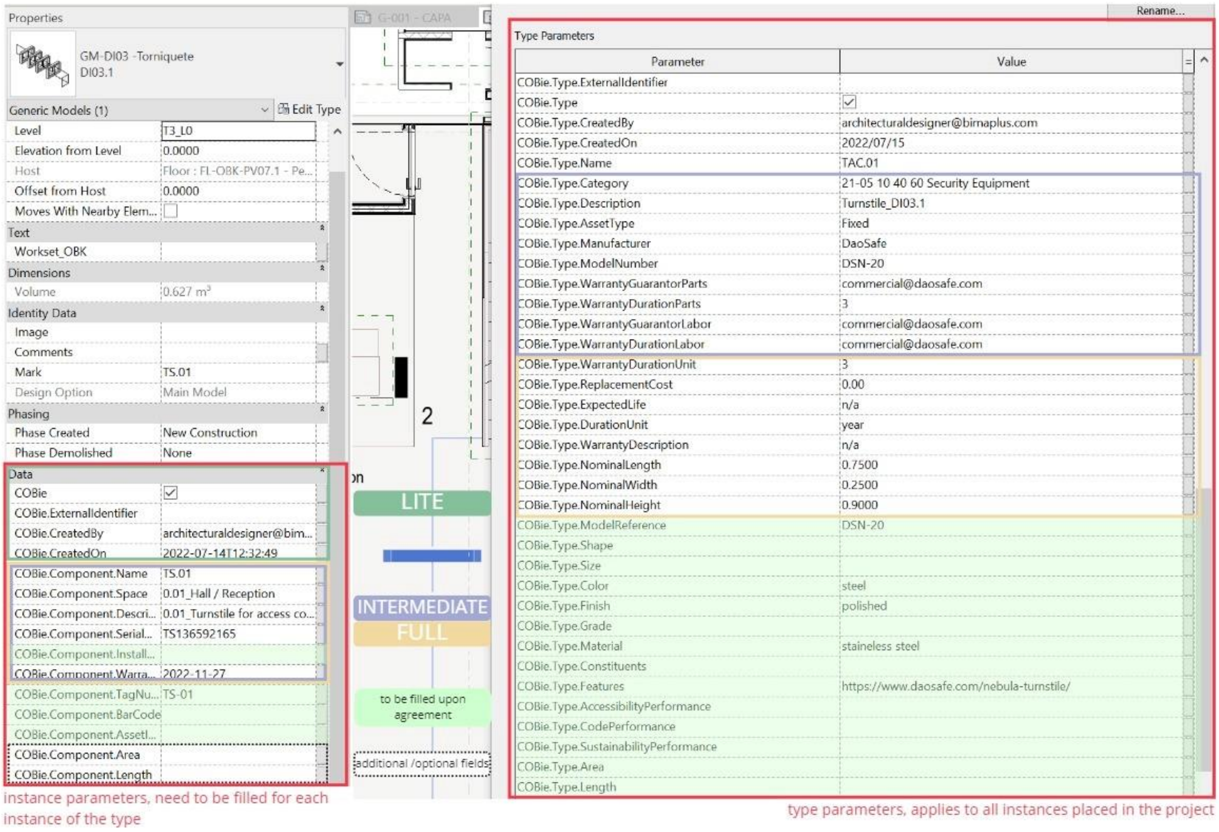

Figure 70 – COBie attributes filled inside Revit – Turnstile example

HVAC elements feature more elaborated hierarchies when compared to the previous examples, as Figure 71 demonstrates. One system (INS.49) can be composed of several components (four flex ducts, two rectangular ducts, one elbow transition, one rectangular duct transition and one fan coil unit) of different types (flex ducts, rectangular ducts and fan coil unit). Additionally, one component (the fan coil unit) can be part of two different systems (INS.49 and RET.49). Nevertheless, in more complex HVAC nets, subsystems can be found in major systems, and a convention should be established to ease the data transfer and the user perception.

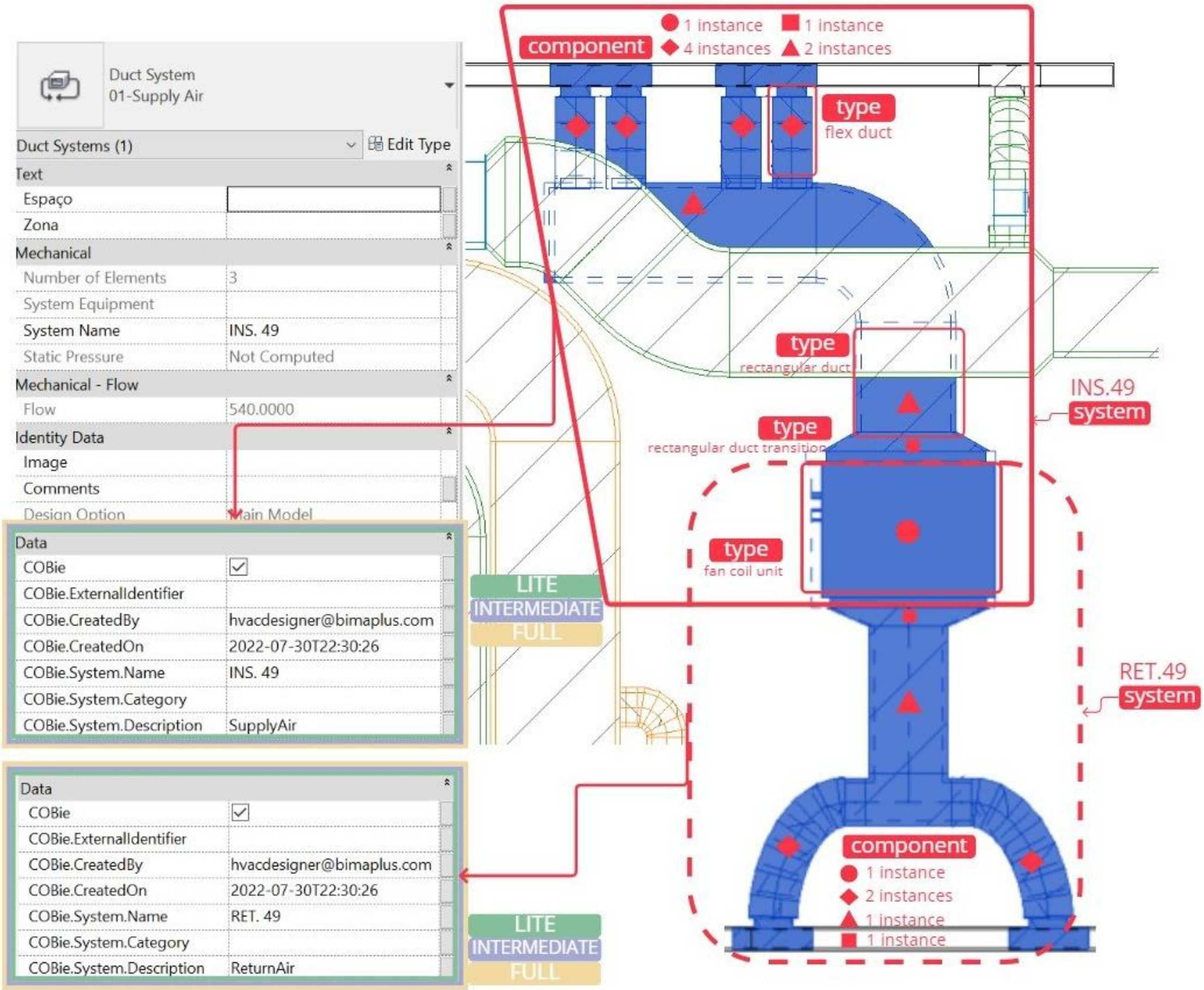

Figure 71 – HVAC COBie.Systems inside Revit

5.3. COBie Planner results in Dalux

As an encore to the building information lifecycle, a test project was created on an IWMS solution that contains, in addition to others, specific modules to O&M/FM. The chosen platform was Dalux since it is a software that counts with several major models and functions and that from the beginning was available to provide a student license to make the final phase of this dissertation possible. Dalux offers a range of categories which contain multiple modules, such as a free “Viewer”; “Box”, the “home” of all documentation; “Field” aimed at contractors; “Tender”, for creating and organizing tenders; “Handover”, to generally deal with assets and FM, aimed at facility managers and owners. All of them can be combined and customized to the organization's needs.

For this dissertation, the modules of Handover and FM were used, to check how the model can be managed after it is exported from the authoring software. Inside the Handover module, there are several functionalities available, but for the context of this work, only the basic features were activated (“Box Light” as can be seen in Figure 72). The same principle applies to the FM module.

The integration from authoring software to Dalux is made by an add-in. In this case study and as shown in the previous section, Revit was used as the authoring tool. Nevertheless, Dalux is also available for other tools, as shown in Chapter 3, p.37. The main goal of this integration was to validate if the data could be imported directly from the COBie.xlsx sheet, followed by a second goal which was to inspect the transferred data to the IWMS software. The same examples from the previous section – COBie Planner integration with Planerly platform and COBie Planner in use inside authoring software – were considered. This strategy was adopted aiming to provide a logical sequence for the reader.

Models can be uploaded to Dalux through a plugin installed in the authoring software. Before the upload, it is required to have a project created in Dalux – Figure 72. After creating the project, the user can fill in basic information regarding users, location, teams, and contractual needs, amongst others. Those will not be shown in this case study due to confidentiality reasons. When uploading the model, the user is given different check boxes to confirm the upload of the 3D model, the rooms, and/or the 2D documentation. This is because Dalux recognizes not only the 3D model but also the 2D documentation, such as drawings in sheets in the model, so when uploading from Revit to Dalux, it is necessary to map the levels to the plans, as well as to verify the values of the levels. This process is presented in detail in Appendix 10.

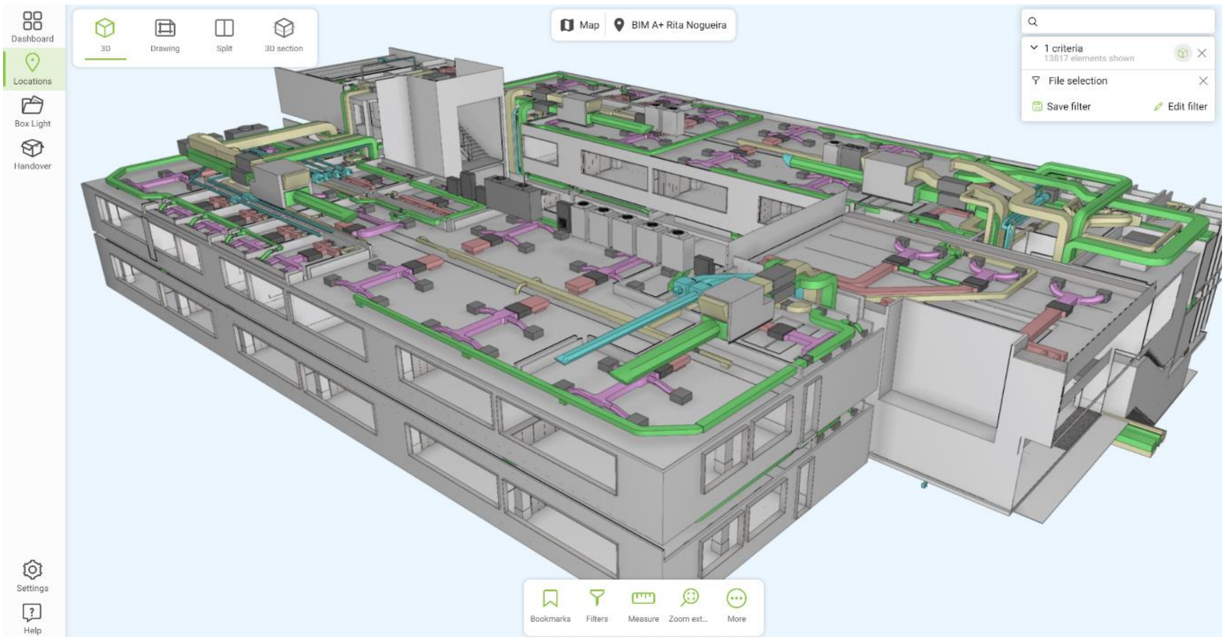

Figure 72 – Project appearance in Dalux

Two models were exported to Dalux Handover and FM, both Architectural and HVAC models. The initial idea was to export to the Handover module and then update the FM from it, which would avoid double exportation from authoring software, however, in the course of the work and with the clarification of the Dalux support, it was realized that this action is only possible with the help of a Dalux CSM (Common Service Model). A Dalux FM installation is created by using the API (Application Programming Interface) key that brings all the relevant data directly to the FM platform. Considering the timeframe available for this dissertation, it was a complex procedure to implement and not so relevant to the result. Although it was not used in the presented case study, it is important to note that it is possible to be implemented in a corporate context and it simplifies the user's tasks.

COBie attributes filled in the authoring software are automatically visible in Dalux environment. Another option available is to import the COBie spreadsheet file into Dalux Handover. With the API integration described before, those will also be synchronized to Dalux FM. Export COBie information from Dalux Handover is also possible, the software will create a spreadsheet with all the available assets.

It is significant to mention that Spaces are not assets by default, so to have spaces in the COBie file exported from Dalux, assets must be created first. Thus, Spaces constitute an exception, as they don't own attributes or components, so they are not automatically recognized by the software from the .xlsx sheet. Figure 73. Plus, Dalux automatically creates a Room tag with the number, name, area, and Cobie.Space.Description – Figure 73.

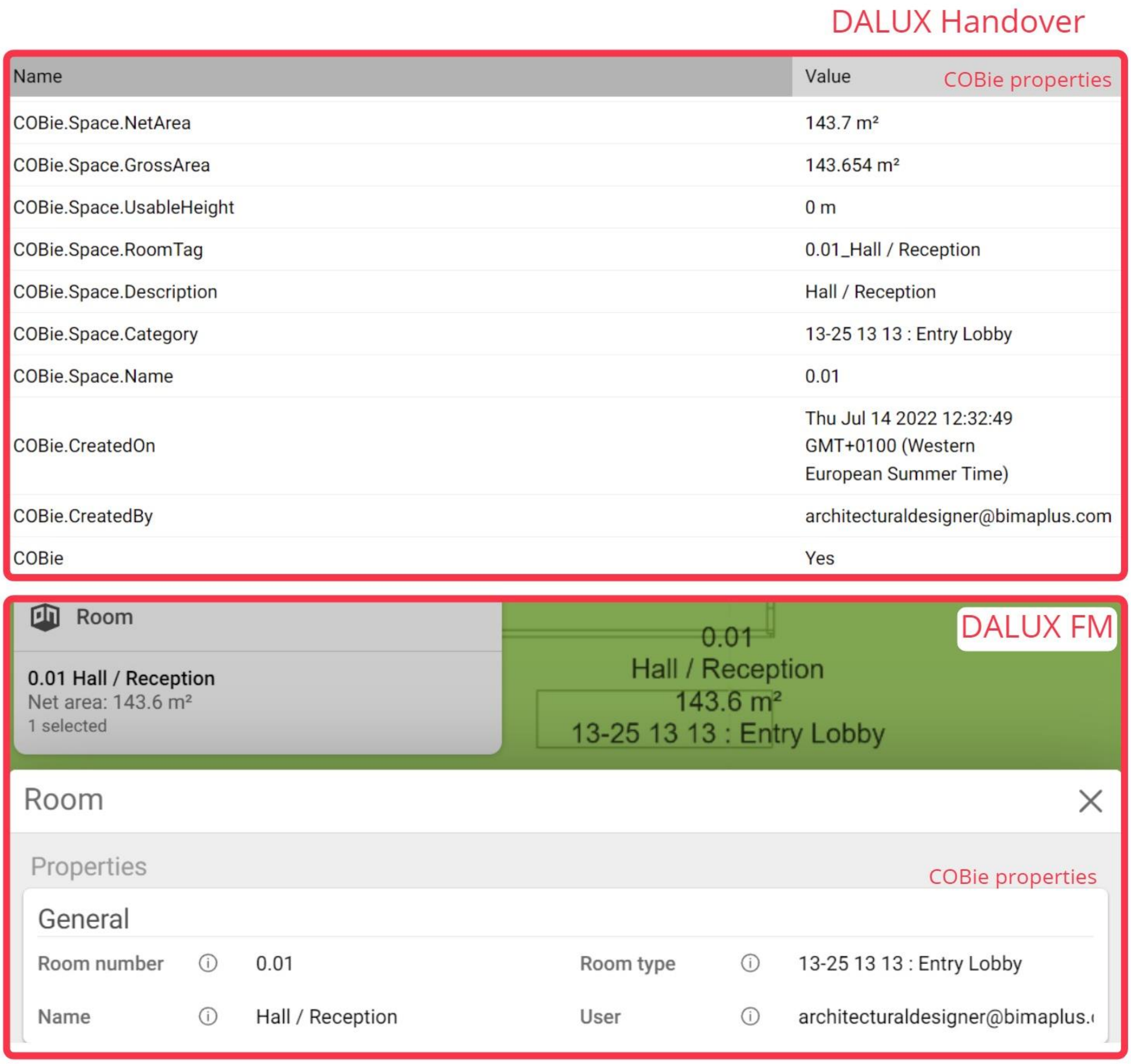

Figure 73 – COBie.Space in Dalux Handover and FM

For the Turnstile and the Fan Coil Unit, the result is similar, as all the COBie Properties are visible both in Dalux Handover – Figure 75 and Figure 74, – and Dalux FM – Figure 76 and Figure 77. Blank fields inside the authoring software are automatically hidden by Dalux.

In Dalux FM location and asset information is shown, along with an asset quick view that contains the classification code, the category, level, and location. In the Product section is possible to edit the information and attach other files like pictures (.jpg), written documents (.doc .docx, .txt) , datasheets (.pdf), or other considered of interest.

DALUX Handover

COBie properties

Data	COBie	Yes
Data	COBie.Component.Description	2 Pipe Fan Coil Heating and Cooling Units
Data	COBie.Component.Name	VRVI.3.09
Data	COBie.Component.Space	0.24_External MeetingRoom
Data	COBie.Component.WarrantyStartDate	2022/19/30
Data	COBie.CreatedBy	hvacdesigner@bimaplus.com
Data	COBie.CreatedOn	Sat Jul 30 2022 22:30:27 GMT+0100 (Western European Summer Time)
Data	COBie.Type	Yes
Data	COBie.Type.AssetType	Fixed
Data	COBie.Type.Category	21-04 30 30 10 : Central Cooling
Data	COBie.Type.CreatedBy	hvacdesigner@bimaplus.com
Data	COBie.Type.CreatedOn	Sat Jul 30 2022 22:30:32 GMT+0100 (Western European Summer Time)
Data	COBie.Type.Description	Fan Coil Unit
Data	COBie.Type.DurationUnit	year
Data	COBie.Type.Features	https://www.daikin.pt/pt_pt/product
Data	COBie.Type.Manufacturer	Daikin
Data	COBie.Type.ModelNumber	FSXQ-A
Data	COBie.Type.Name	FCU
Data	COBie.Type.NominalHeight	0.3 m
Data	COBie.Type.NominalLength	0.1 m
Data	COBie.Type.NominalWidth	0.7 m
Data	COBie.Type.Shape	rectangular
Data	COBie.Type.WarrantyDurationLabor	commercial@daikin.com
Data	COBie.Type.WarrantyDurationParts	3
Data	COBie.Type.WarrantyDurationUnit	year
Data	COBie.Type.WarrantyGuarantorLabor	commercial@daikin.com
Data	COBie.Type.WarrantyGuarantorParts	commercial@daikin.com

Figure 74 – HVAC COBie.Type inside Dalux Handover

DALUX Handover

COBie properties

Data	COBie	Yes
Data	COBie.Component.Description	0.01_Turnstile for access control
Data	COBie.Component.InstallationDate	2022-11-27
Data	COBie.Component.Name	TS.01
Data	COBie.Component.SerialNumber	TS136592165
Data	COBie.Component.Space	0.01_Hall / Reception
Data	COBie.Component.TagNumber	TS-01
Data	COBie.Component.WarrantyStartDate	2022-11-27
Data	COBie.CreatedBy	architecturaldesigner@bimaplus.com
Data	COBie.CreatedOn	Thu Jul 14 2022 12:32:49 GMT+0100 (Western European Summer Time)
Data	COBie.Type	Yes
Data	COBie.Type.AssetType	Fixed
Data	COBie.Type.Category	21-05 10 40 60 Security Equipment
Data	COBie.Type.Color	steel
Data	COBie.Type.CreatedBy	architecturaldesigner@bimaplus.com
Data	COBie.Type.CreatedOn	2022/07/15
Data	COBie.Type.Description	Turnstile_DI03.1
Data	COBie.Type.DurationUnit	year
Data	COBie.Type.ExpectedLife	n/a
Data	COBie.Type.Features	https://www.daosafe.com/nebula-turnstile/
Data	COBie.Type.Finish	polished
Data	COBie.Type.Manufacturer	DaoSafe
Data	COBie.Type.Material	staineless steel
Data	COBie.Type.ModelNumber	DSN-20
Data	COBie.Type.ModelReference	DSN-20
Data	COBie.Type.Name	TAC.01
Data	COBie.Type.NominalHeight	0.9 m
Data	COBie.Type.NominalLength	0.75 m
Data	COBie.Type.NominalWidth	0.25 m
Data	COBie.Type.ReplacementCost	0 $
Data	COBie.Type.WarrantyDescription	n/a
Data	COBie.Type.WarrantyDurationLabor	commercial@daosafe.com
Data	COBie.Type.WarrantyDurationParts	3
Data	COBie.Type.WarrantyDurationUnit	3
Data	COBie.Type.WarrantyGuarantorLabor	commercial@daosafe.com
Data	COBie.Type.WarrantyGuarantorParts	commercial@daosafe.com

Figure 75 – Turnstile Example in Dalux Handover

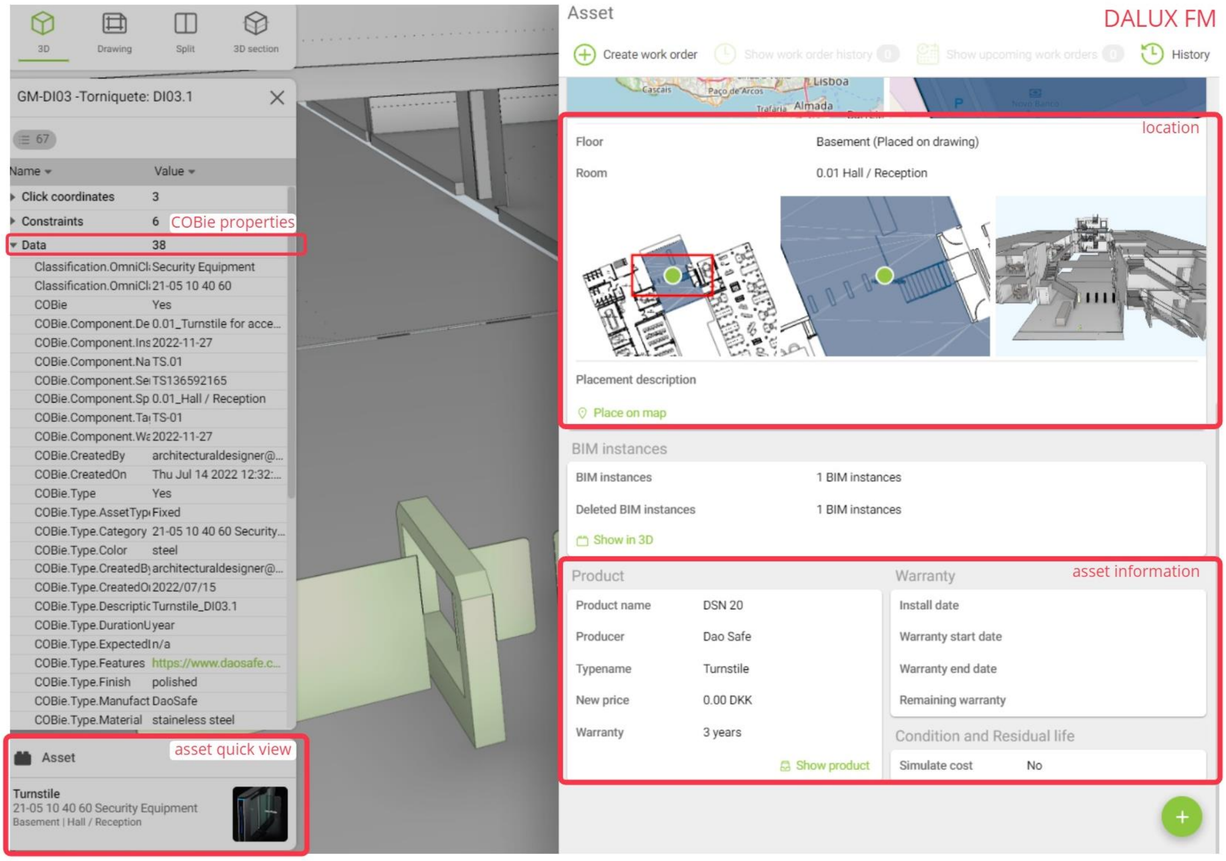

Figure 76 – Turnstile Example in Dalux FM

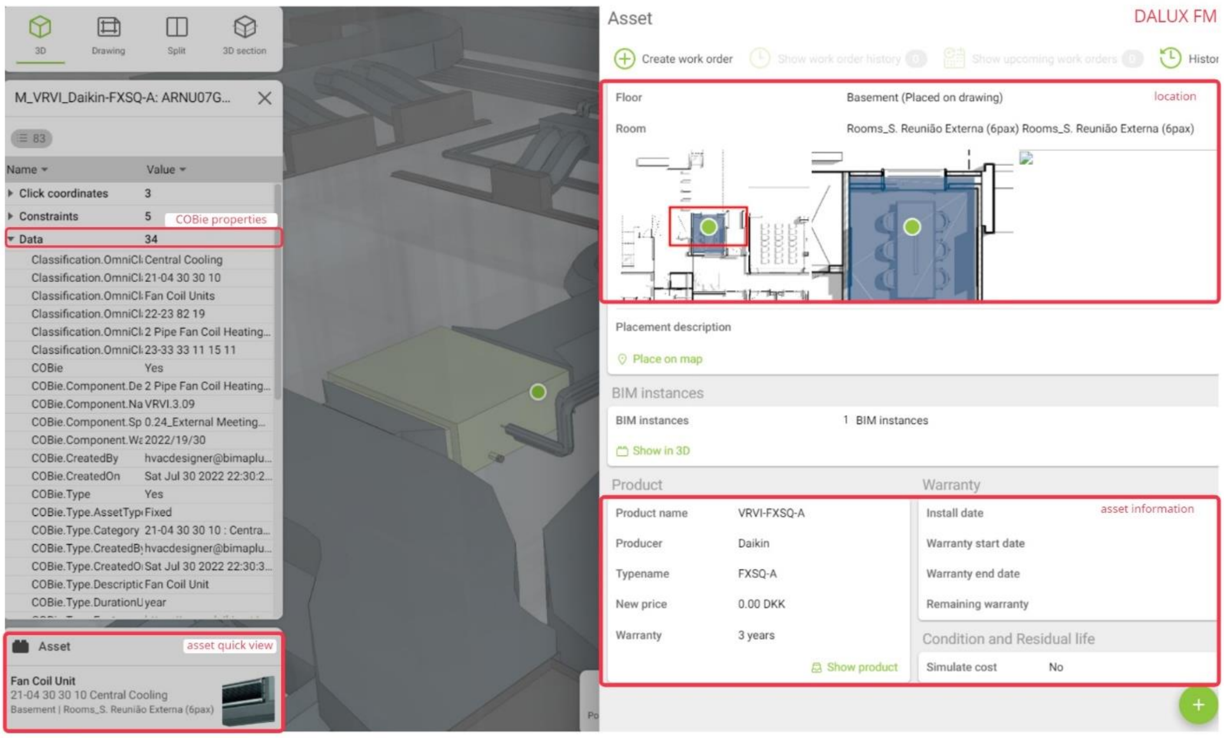

Figure 77 – HVAC COBie.Type inside Dalux FM

6. CONCLUSIONS & FUTURE RESEARCH

BIM comprises the act of creating and managing information during a building life cycle and by deploying its use since early stages of the project, the realization of its full potential increases. Throughout the building's development span, a considerable amount of information remains unrecorded and unsorted for future use. This information loss is a result of data input that is done manually based on outdated procedures. Integrating facility data via BIM throughout all the phases of the building process, allows owners and operators to be given more effective and efficient buildings, enhancing a better management regarding O&M.

However, a lower adoption rate among industry professionals is still observable when compared to project stages, triggered by multiple factors. Short experience with BIM's whole-life application, the unmeasured contribution of as-built information to FM, and the lack of clear definition of roles, responsibilities, and data requirements are key factors found throughout this investigation.

Understanding possibilities regarding BIM-FM linking procedures combined with early database development during Design stage, avoids later re-creation of data by third parties. Real-time inventory mapping within the digital asset management solutions is allowed by direct integration of the authoring software with the O&M/FM solution or through COBie. By not being attached to any specific proprietary middleware solution and being compatible with both authoring and FM software solutions, COBie stands out as facilitator regarding interoperability issues. Designers, contractors, and facility managers may collaborate on data due to COBie.

Nevertheless, its complex appearance to a new user should not be underestimated, so the need of a comprehensive guide to enhance the use of this tool within teams was bridged by this dissertation. With a clear understanding of what information is expected, when and how it should be supplied, and who is responsible for providing it, teams can become more motivated and productive.

As this dissertation was developed in liaison with industry and practitioners, its practical application became be pertinent, as a demonstration of the professional usability of the developed tool. As a BIM consulting company, one of LIMSEN's goals is to assist owners to define information requirements, supporting teams in this realization. This is accomplished by using the Plannerly tool as a BEP placeholder, so it was appropriate to incorporate all the knowledge created on COBie into this platform as well, resulting in COBie Planner. Subsequently, and aiming to get closer to the design teams, an example was created in Revit software, so that the information creation process could be visible. Finally, the applicability of COBie as a tool for data exchange and enrichment was tested by the integration with Dalux.

The benefits of a tool as COBie Planner as part of the corporate BEP includes maximizing the value and advantages of BIM to support operations and maintenance management, in addition to improving its efficiency through integration with BIM technology.

Limitations regarding the scope of this dissertation were noted over its course and are presented below, since some of them can be addressed in future research. Firstly, a cross-cutting issue regarding the use of BIM in the field of O&M/FM is simultaneously vast because of the field itself and in a way still embryonic, regarding the processes, challenges, benefits, and outcomes. It was challenging to draw the boundaries of the topics to be addressed, due to the desire to cover all the feasible relevant to the theme, at the risk to develop multiple micro-investigations.

Secondly, it would also have been interesting to receive feedback from various owners and operators about their level of literacy regarding COBie, assessing their understanding about the usability of this tool in O&M phases and thus having an overview of the industry's maturity for the use of COBie as an effective tool for the transmission of information between work phases. To complete this task, it would have been necessary to study the type of questions to be asked and the type of scale to be used for the quantification/qualification of the results obtained, in addition to an analysis and comparison of other similar studies that had already been applied. This would not be possible to fit into the time frame available for the realization of this dissertation.

Finally, based on the structured information with the development of this work, it could be interesting to develop a tool for COBie Planner, external to the Plannerly environment, guaranteeing no dependance from external platforms, and the possibility of using it in other contexts, projects, and teams.

Within the scope of the life of BIM models, beyond operation, maintenance, and use, not being a new concept, Digital Twin (DT) is increasingly gaining strength in the AECO/O industry, based on the motto of starting digital, staying digital and delivering digital. Digital handover accelerates operational readiness by starting with the end in mind and harnessing the BIM process to hand over a Digital Twin. Operations became smarter, gaining efficiency and improving the occupant experience, by leveraging the digital twin's reflection of assets, spaces, and systems.

Facing the previous statement, the continual interaction between physical and digital representations of assets is a key component in the development of DT. Data must be updated in both directions to maintain alignment between the physical and digital components. Digital Twin allows travelling in time, with past and upcoming maintenance events possibility of the report. Nevertheless, it relies on previous data availability, accuracy, and structure. The interoperability challenge regarding data can be surpassed using COBie, relying on structured and verifiable information that can enhance and guarantee a solid basis for the recirculation of information for the entire life of the building.

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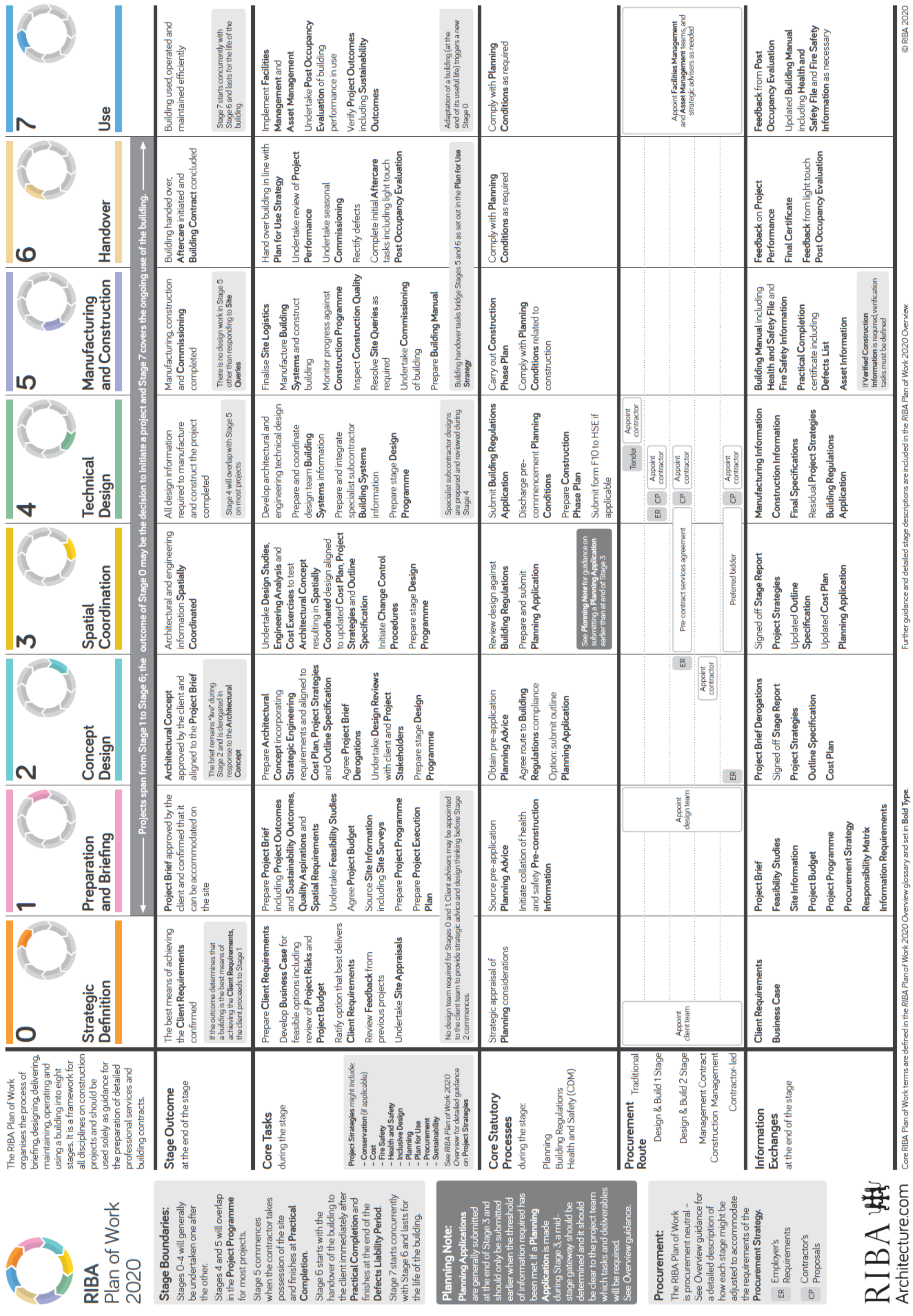
LIST OF ACRONYMS AND ABBREVIATIONS

AECO/O	Architecture, Engineering, Construction, Operation & Owners
AI	Artificial Intelligence
AIM	Asset Information Model
AM	Asset Management
AR	Augmented Reality
BS	British Standards
BAS	Building Automation Systems
BEP	BIM Execution Plan
BIM	Building Information Modelling
CAFM	Computer-Aided Facility Management
CDE	Common Data Environment
CMMS	Computerized Maintenance Management Systems
COBie	Construction Operations Building Information Exchange
DT	Digital Twin
EDMS	Electronic Document Management Systems
EAM	Enterprise Asset Management
FM	Facility Management
IoT	Internet of Things
IT	Information Technology
IWMS	Integrated Workplace Management System
ISO	International Organization for Standardization
O&M	Operations and Maintenance
PIM	Project Information Model
PAS	Public Available Specifications
VR	Virtual Reality

APPENDICES

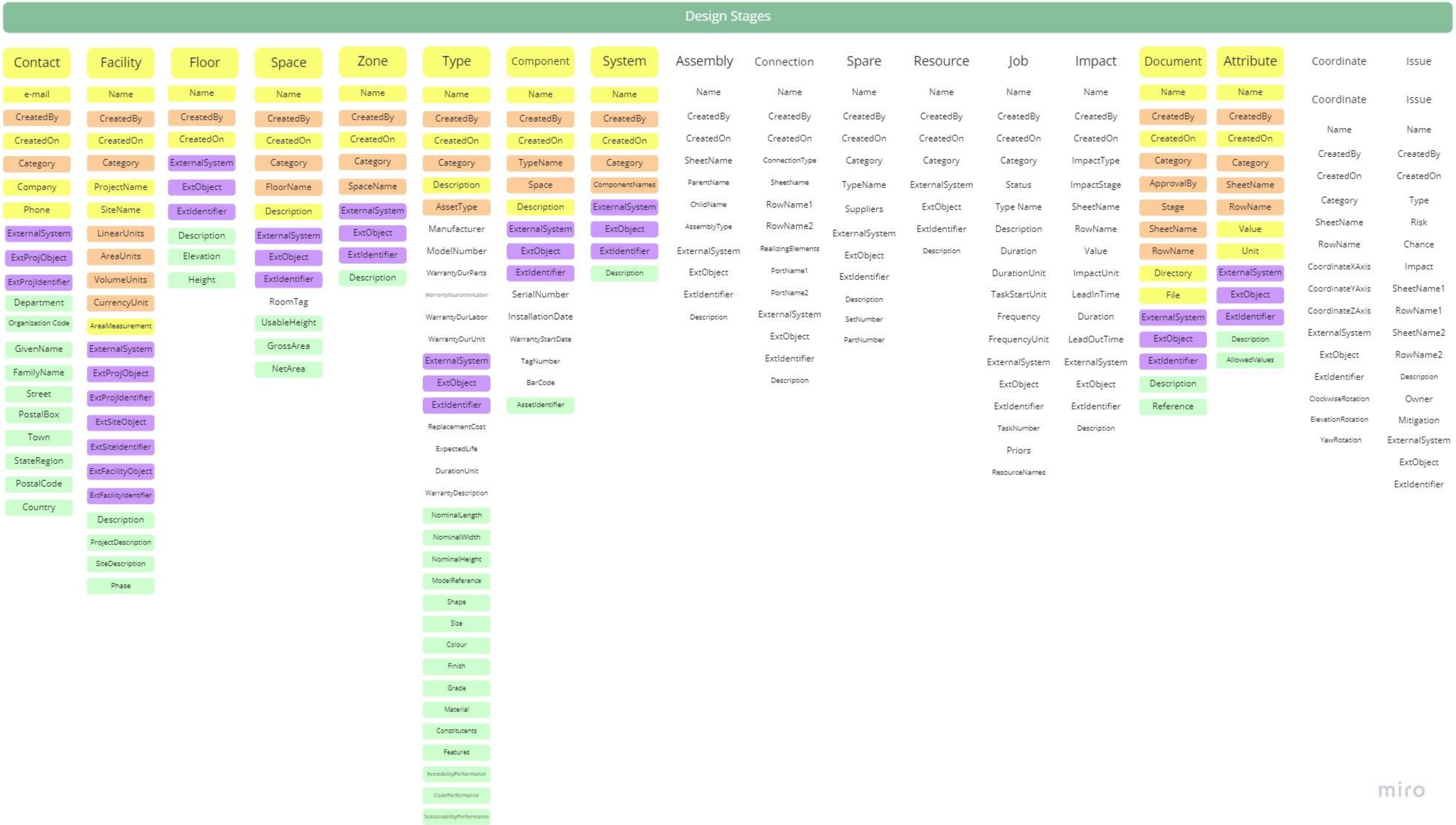
APPENDIX 1: RIBA PLAN OF WORK



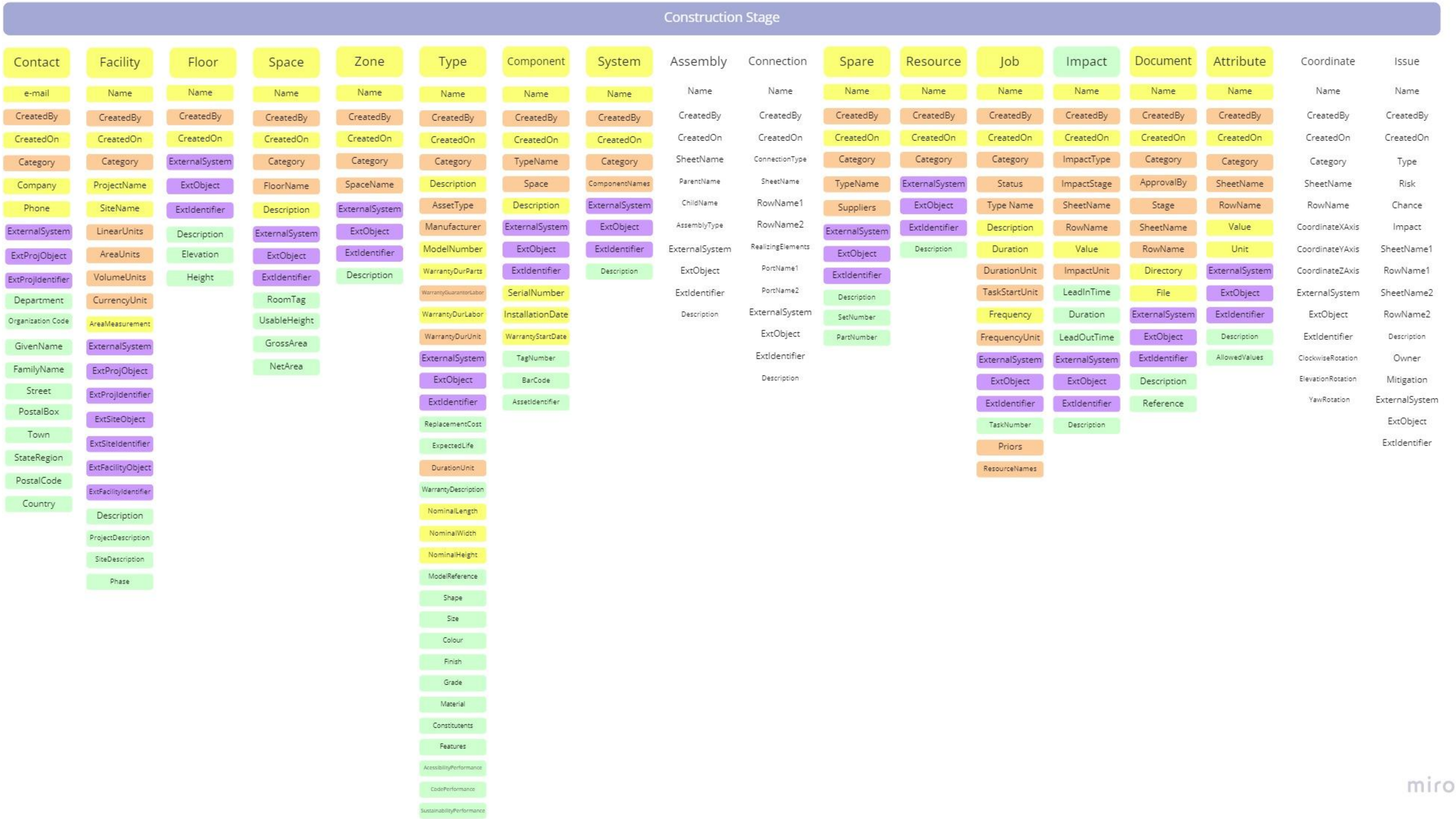
APPENDIX 2: DIGITAL ASSET MANAGEMENT SAAS ASSESSMENT

Vendor		iOffice+SpaceIQ	Dalux	IBM	Autodesk	Autodesk	Nemetcheck	Nemetcheck	Planon	Bentley
SOFTWARE		**Archibus**	**Handover, FM**	**Maximo**	**Tandem**	**360Ops**	**Spacewell**	**ArchiFM**	**Planon Universe**	**iTwin**
Integration with BIM Software		Smart Client Extension4	PlugIn	ModelStream	BIM 360	BIM360	MCS+Bimplus	Bimplus	Plannon Connect	AssetWise+PlanSight,
Interoperability		Revit	Revit, Archicad, Navisworks	Revit	Revit	Revit	Revit, Allplan, Solibri, Archicad	Archicad	Revit	Bentley Design tools, AVEVA, Hexagon, Autodesk
Type of SaaS		IVWS	IVWS	IVWS	digital twin platform	IVWS	IWMS	IVWS	IWMS	IWMS
Authentication		email+password	email+password	email+password	autodesk account	autodesk account	email+password	email+password	email+password	email+password
Devices		desktop, mobile	web-based, desktop, mobile	web-based, desktop, mobile	web-based	web-based, mobile	web-based,desktop, mobile	web-based, desktop, mobile	desktop, mobile	web-based, mobile
Features	Integration	bidirectional	still	biderctional	bidirectional	still	bidirectional	bidirectional	bidirectional	bidirectional
	Cobie Import	yes, through connector	yes	yes	no	no	no	no	yes	no
	Cobie Export	yes, through connector	yes	yes	no	no	no	no	yes	no
	Templates	yes	yes	yes	yes	yes	n/a	n/a	n/a	n/a
Basic Features	Search	yes	yes	yes	yes	yes	yes	yes	yes	yes
	Sort	yes	yes	yes	yes	yes	yes	yes	yes	yes
	Grouping	yes	yes	yes	yes	yes	yes	yes	yes	yes
	Favorites	yes	yes	yes	yes	yes	yes	yes	yes	yes
Classification		Masterformat,Omniclass	Omniclass	Omniclass, Uniformat, customized	Masterformat, Uniformat, Uniclass	connected to Revit categories/customized	imported from BIM	imported from BIM	n/a	n/a
Data /Power BI	Dashboards	yes	yes	yes	yes	yes	yes	yes	yes	yes
	Reports	yes	yes	yes	yes	yes	yes	yes	yes	yes
Requests	Tickets	yes	yes	yes	no	yes	yes	yes	yes	yes
	Tasks	yes	yes	yes	no	yes	yes	yes	yes	yes
	Checklists	yes	yes	yes	no	yes	n/a	yes	yes	yes
Equipment	Picture	yes	yes	yes	no	yes	yes	yes	yes	yes
	Model									
	Manufacturer	yes	yes	yes	no	yes	yes	yes	yes	yes
	Serial									
	Warranty	yes	yes	yes	no	yes	yes	yes	yes	yes
	Age/LifeExpectancy	yes	yes	yes	no	yes	yes	yes	yes	yes
	Docs	yes	yes	yes	no	yes	yes	yes	yes	yes
	Maintenance History	yes	yes	yes	no	yes	yes	yes	yes	yes
Instant Communication	Call	yes	no	n/a	no	no	yes	n/a	n/a	n/a
	Message	yes	no	n/a	no	yes	yes	n/a	n/a	n/a
	Email	yes	yes	n/a	no	yes	yes	n/a	n/a	n/a
	Voice Record	yes	no	n/a	no	no	no	n/a	n/a	n/a
Recorded Activity	Add Comments/ Photos	yes	yes	n/a	no	n/a	n/a	n/a	n/a	n/a
	Tag People	yes	yes	n/a	no	n/a	n/a	n/a	n/a	n/a
Technologies	Immersive Visualization		yes	n/a	n/a	n/a	n/a	n/a	n/a	yes
	IoT	yes	n/a	yes	n/a	n/a	yes	n/a	n/a	yes
	Sensor Vendor API	yes	n/a	yes	n/a	n/a	yes	n/a	n/a	yes
	Use Stats	yes	n/a	yes	n/a	n/a	yes	n/a	n/a	yes
	Environmental Conditions	yes	n/a	n/a	n/a	n/a	yes	n/a	n/a	yes

APPENDIX 3: COBIE SPREADSHEET REQUIREMENTS FOR DESIGN STAGE

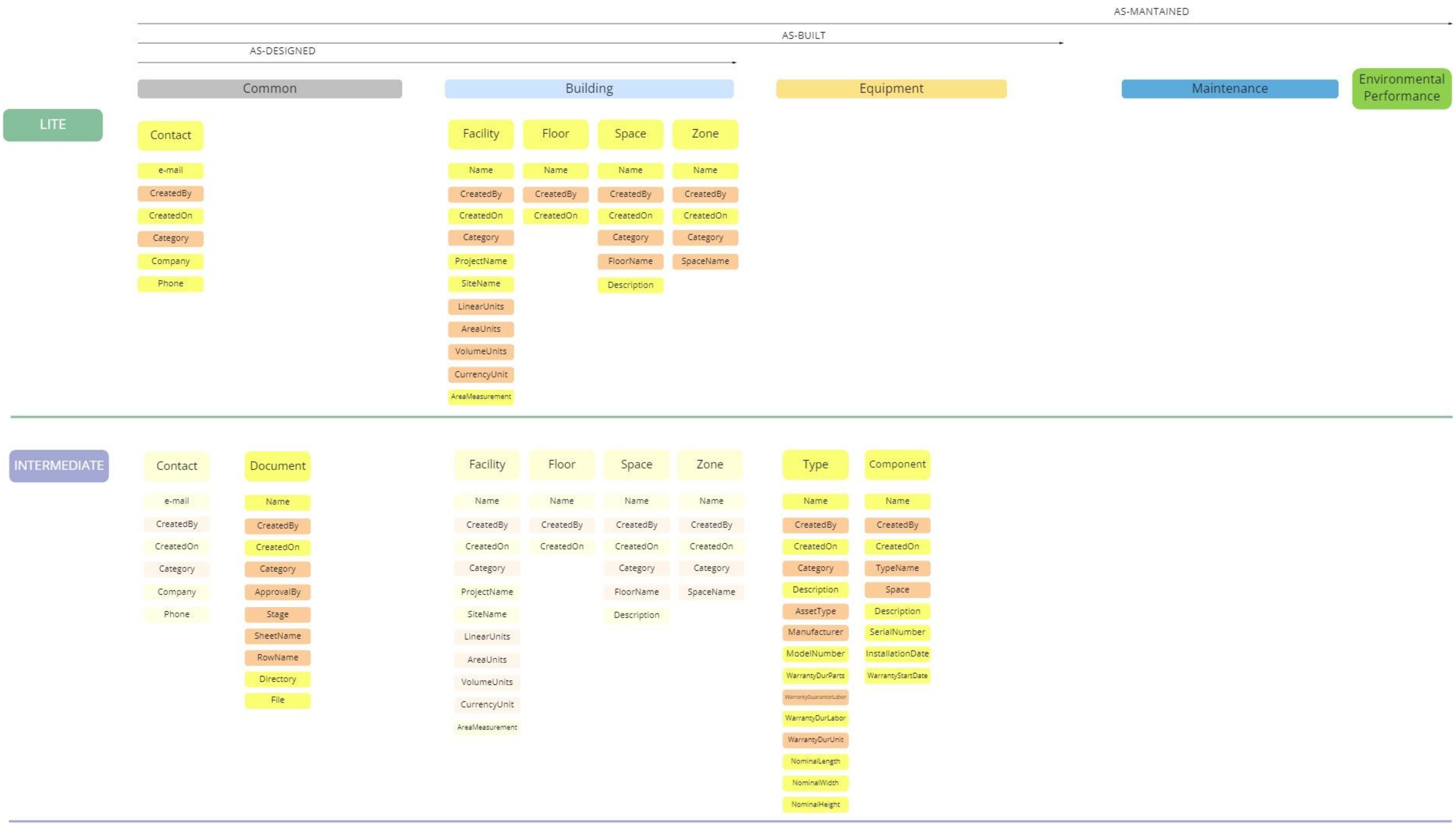


APPENDIX 4: COBIE SPREADSHEET REQUIREMENTS FOR CONSTRUCTION STAGE

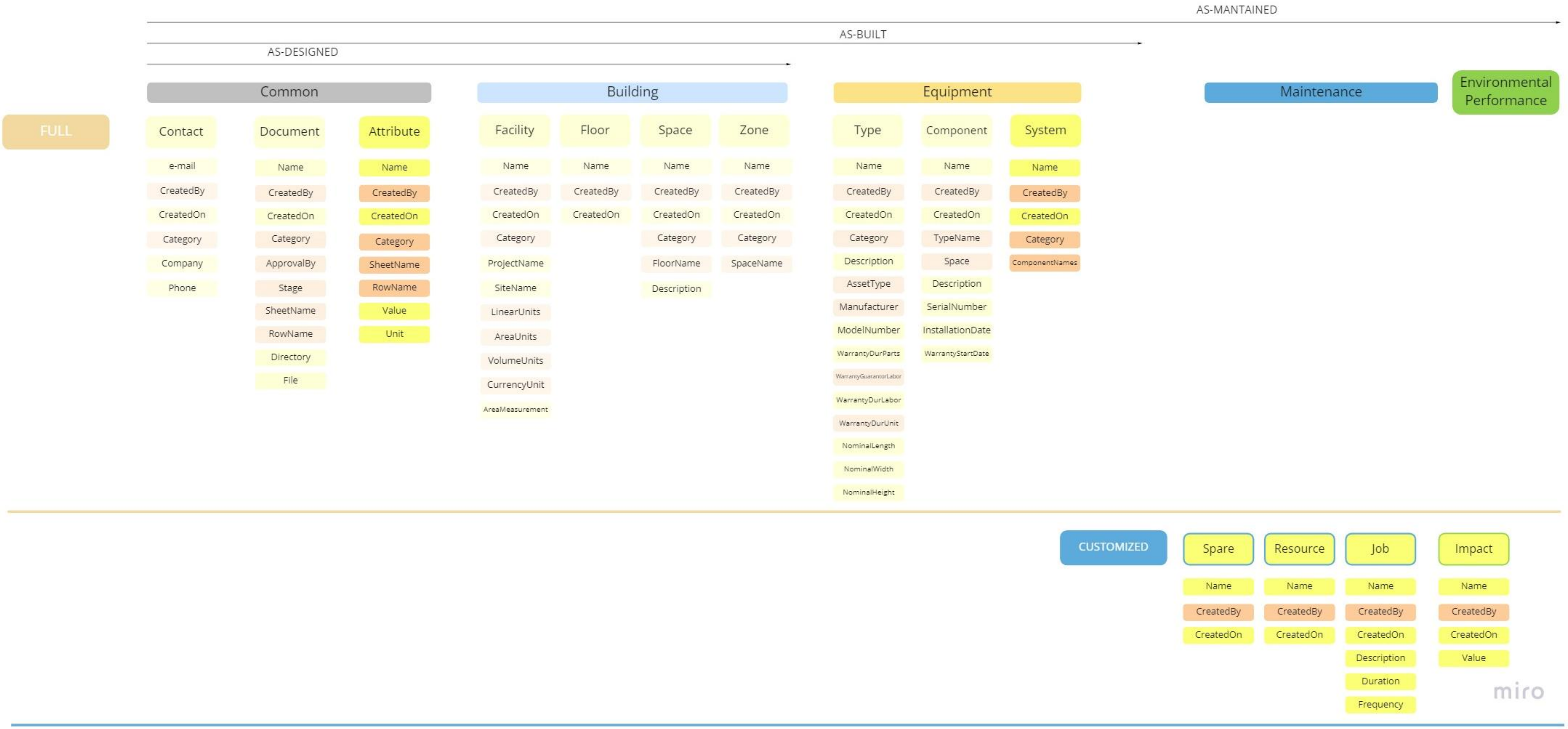


APPENDIX 5: COBIE SPREADSHEET REQUIREMENTS FOR CONSTRUCTION STAGE

APPENDIX 6: COBIE PLANNER LITE AND INTERMEDIATE

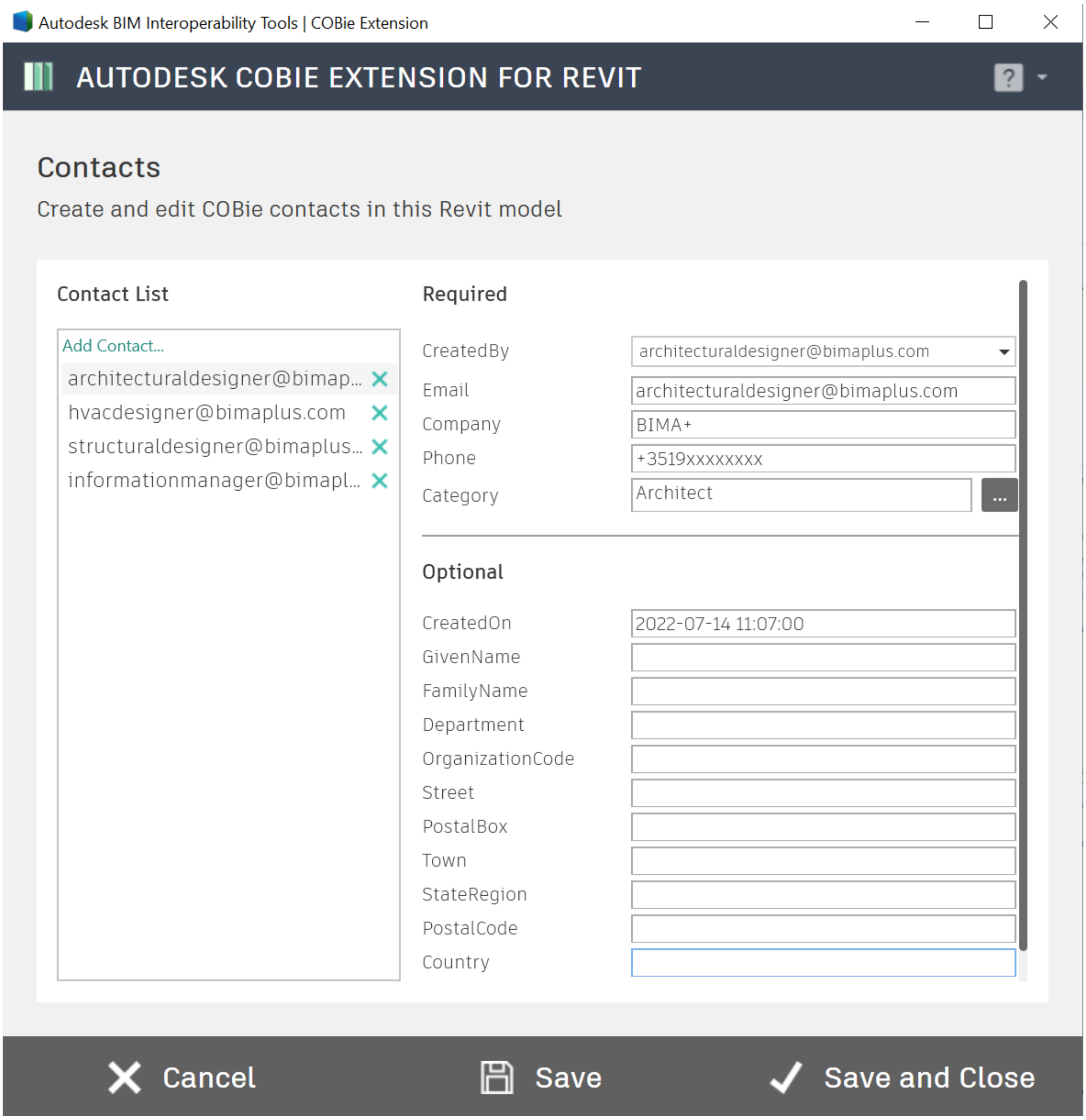


APPENDIX 7: COBIE PLANNER FULL & CUSTOMIZED

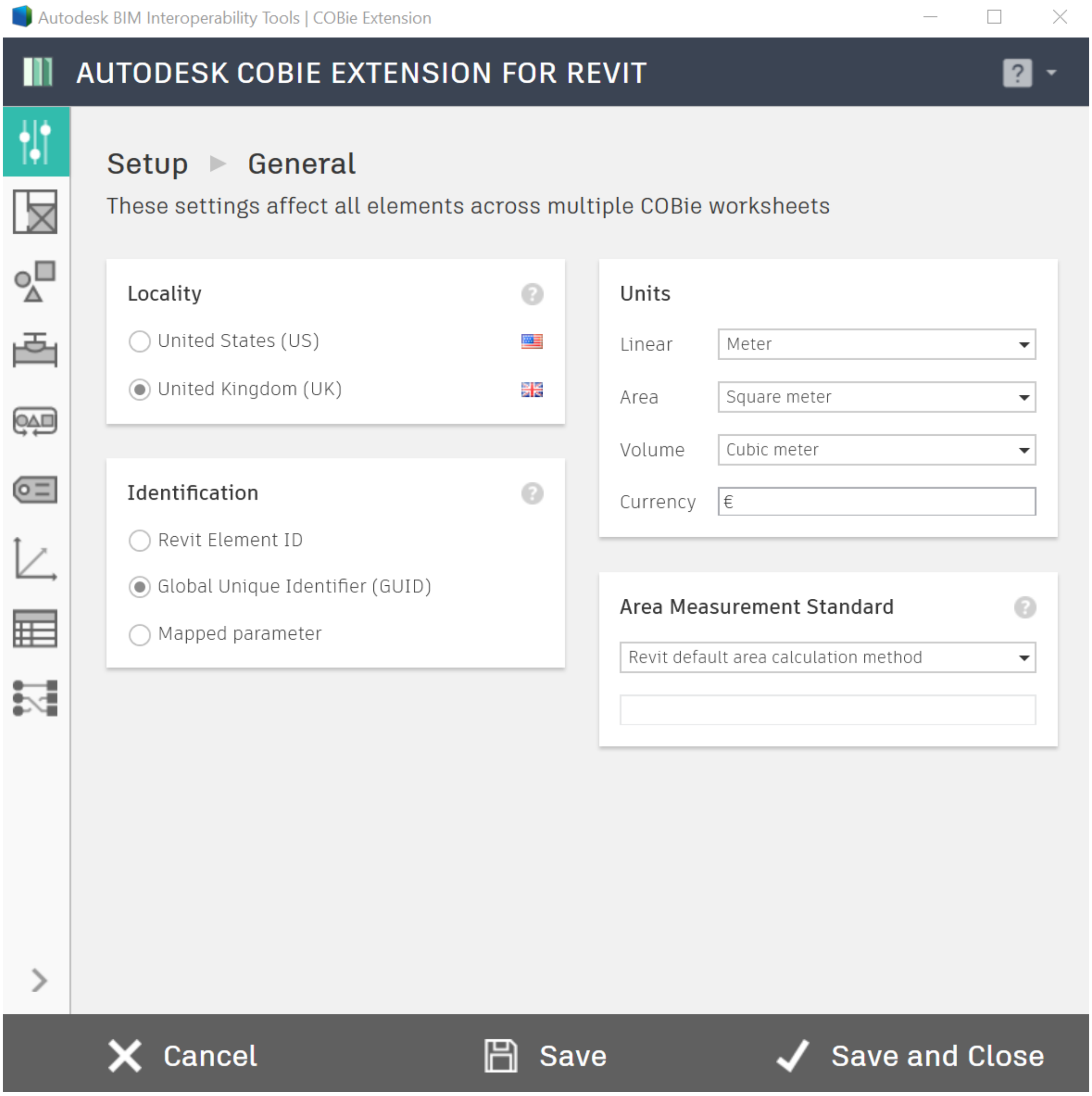


APPENDIX 8: BIM INTEROPERABILITY TOOLS

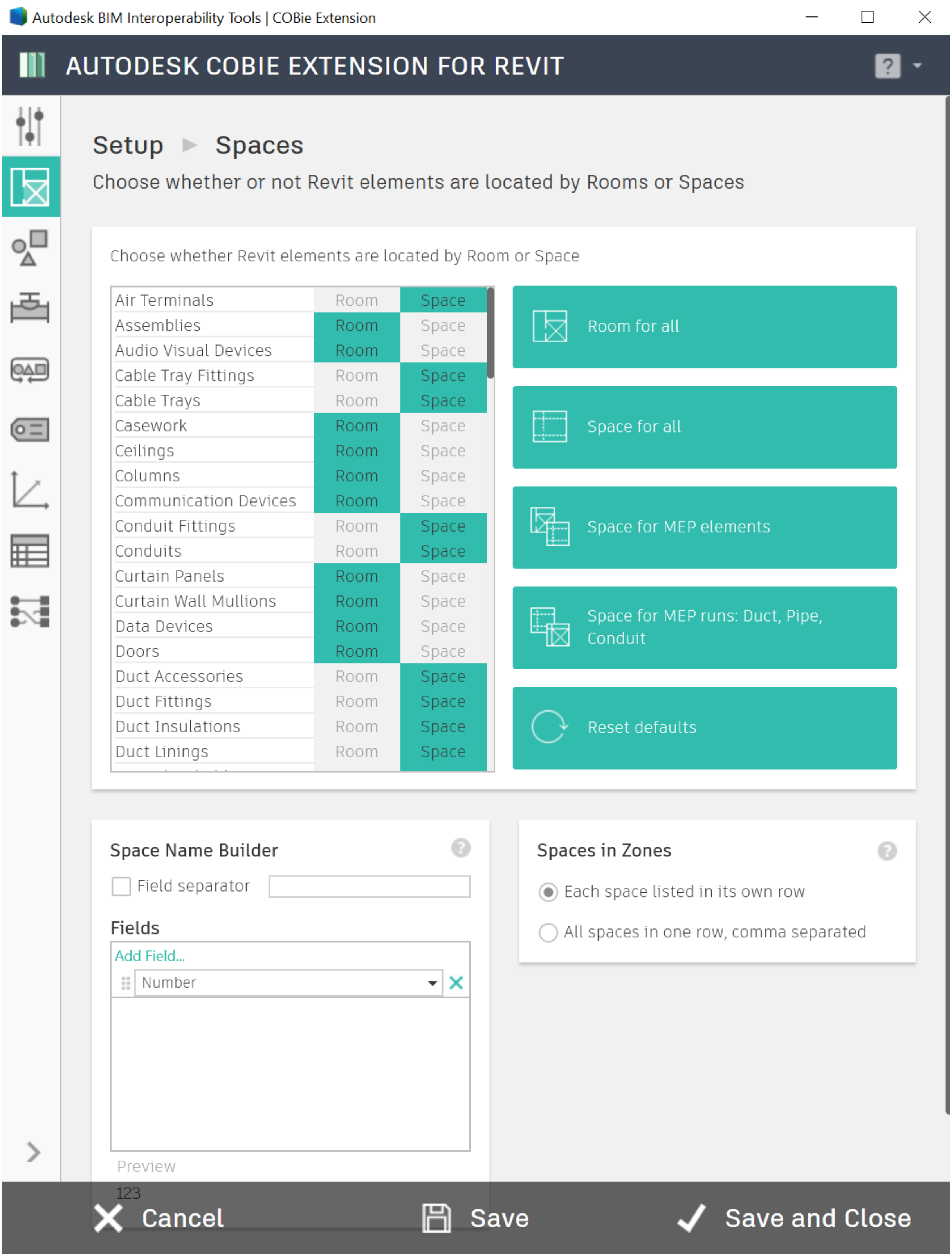
APPENDIX 8A – CONTACTS



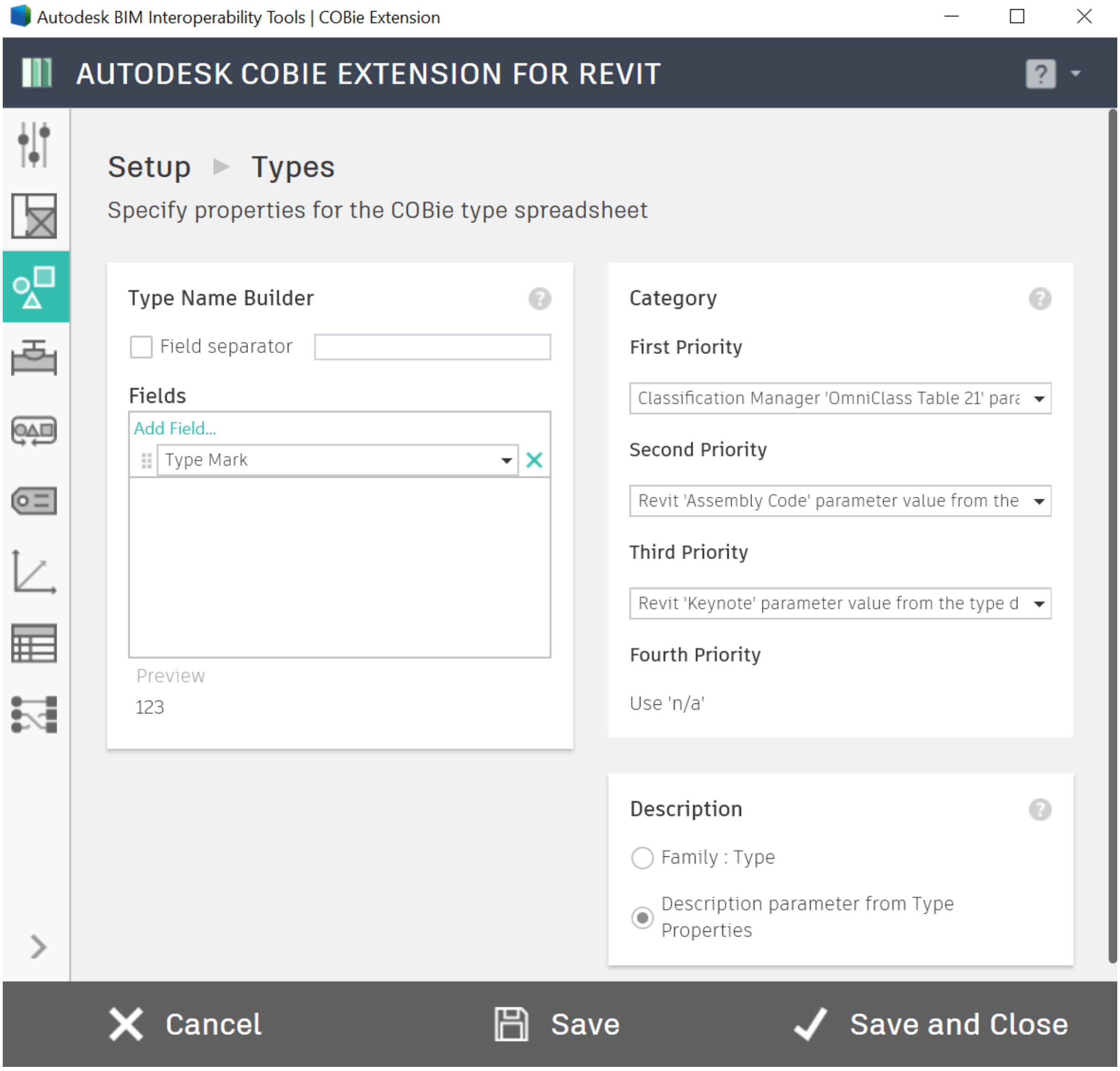
APPENDIX 8B – SETUP–GENERAL



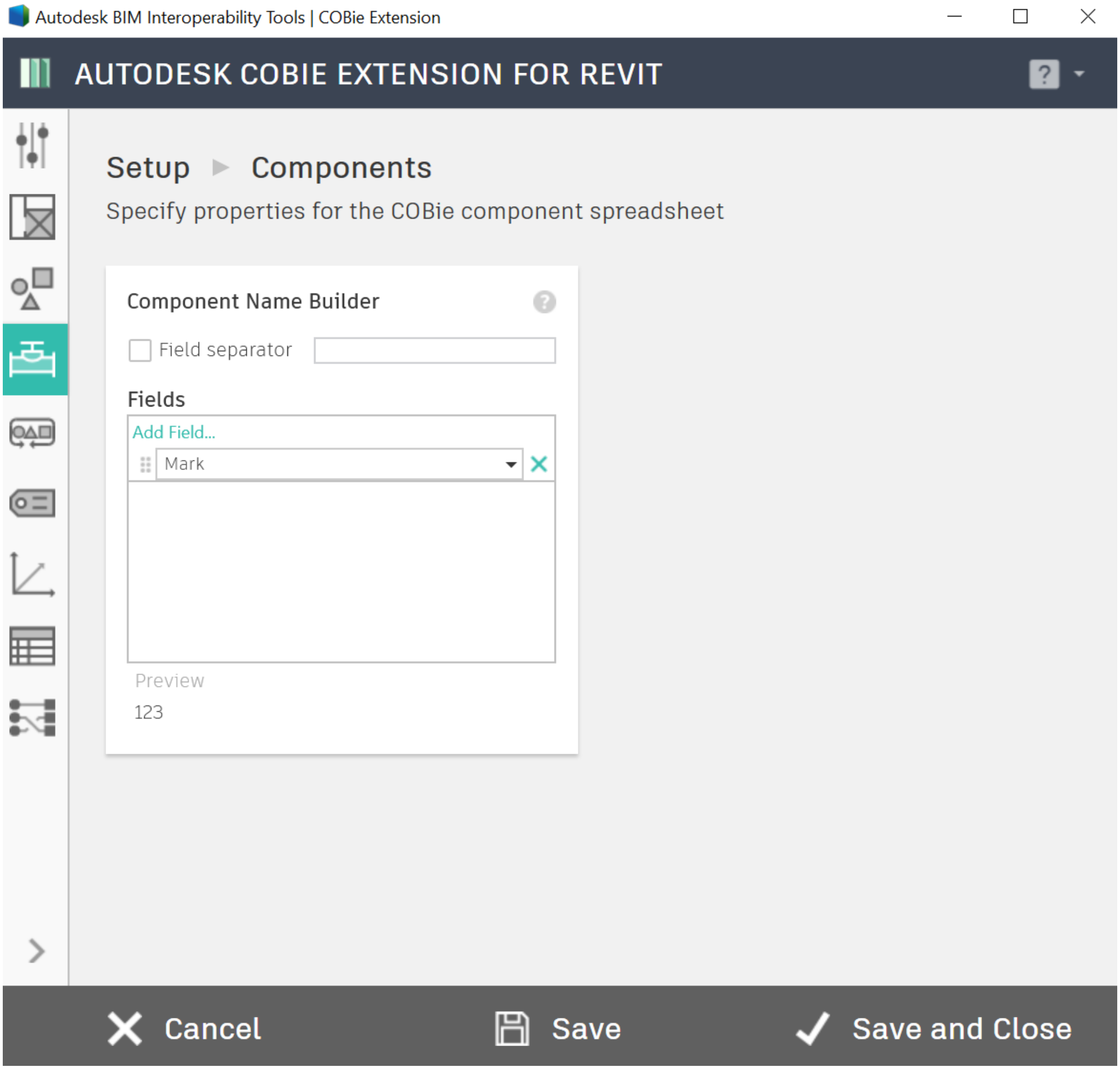
APPENDIX 8C – SETUP–SPACES



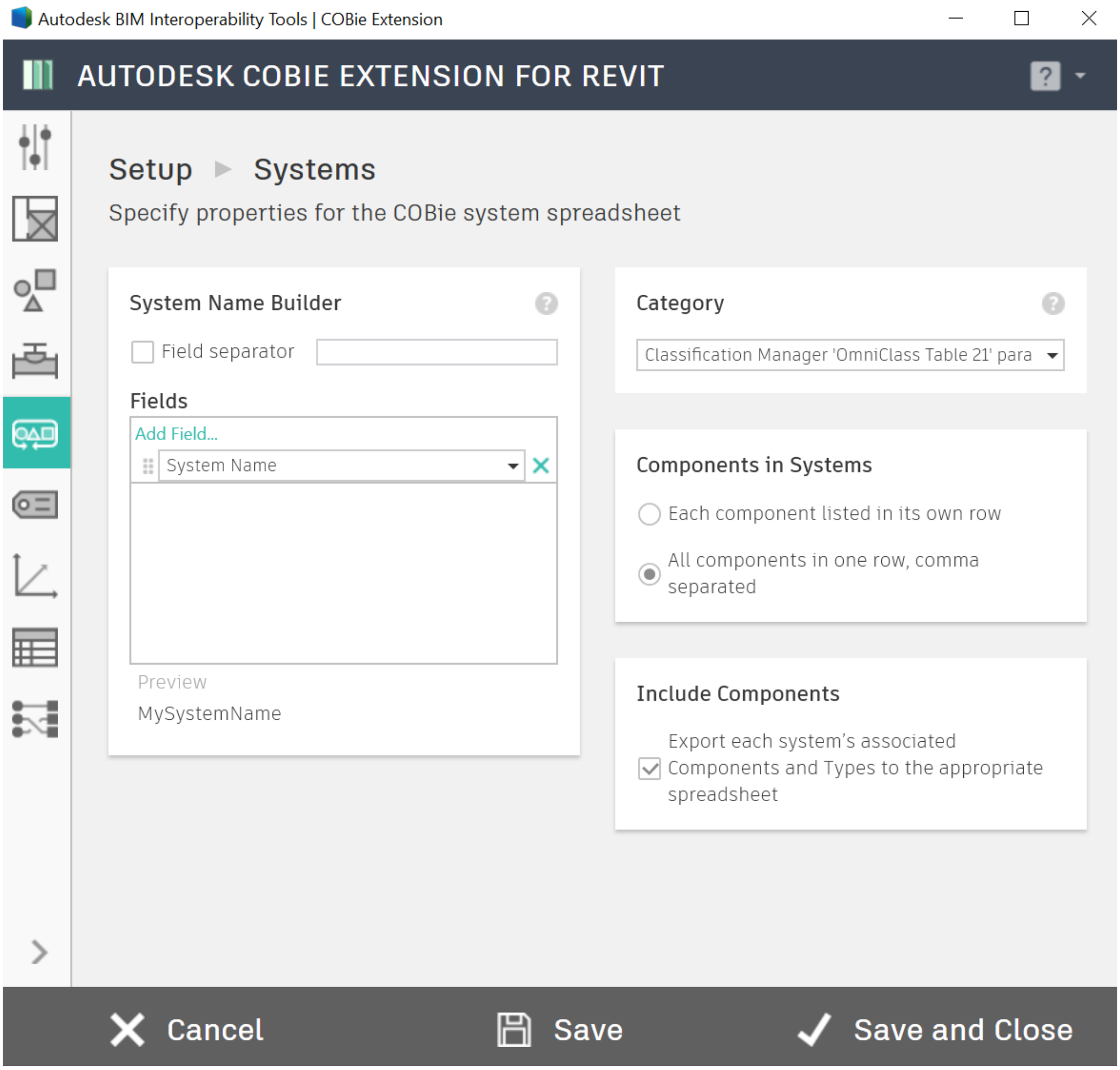
APPENDIX 8D – SETUP–TYPES



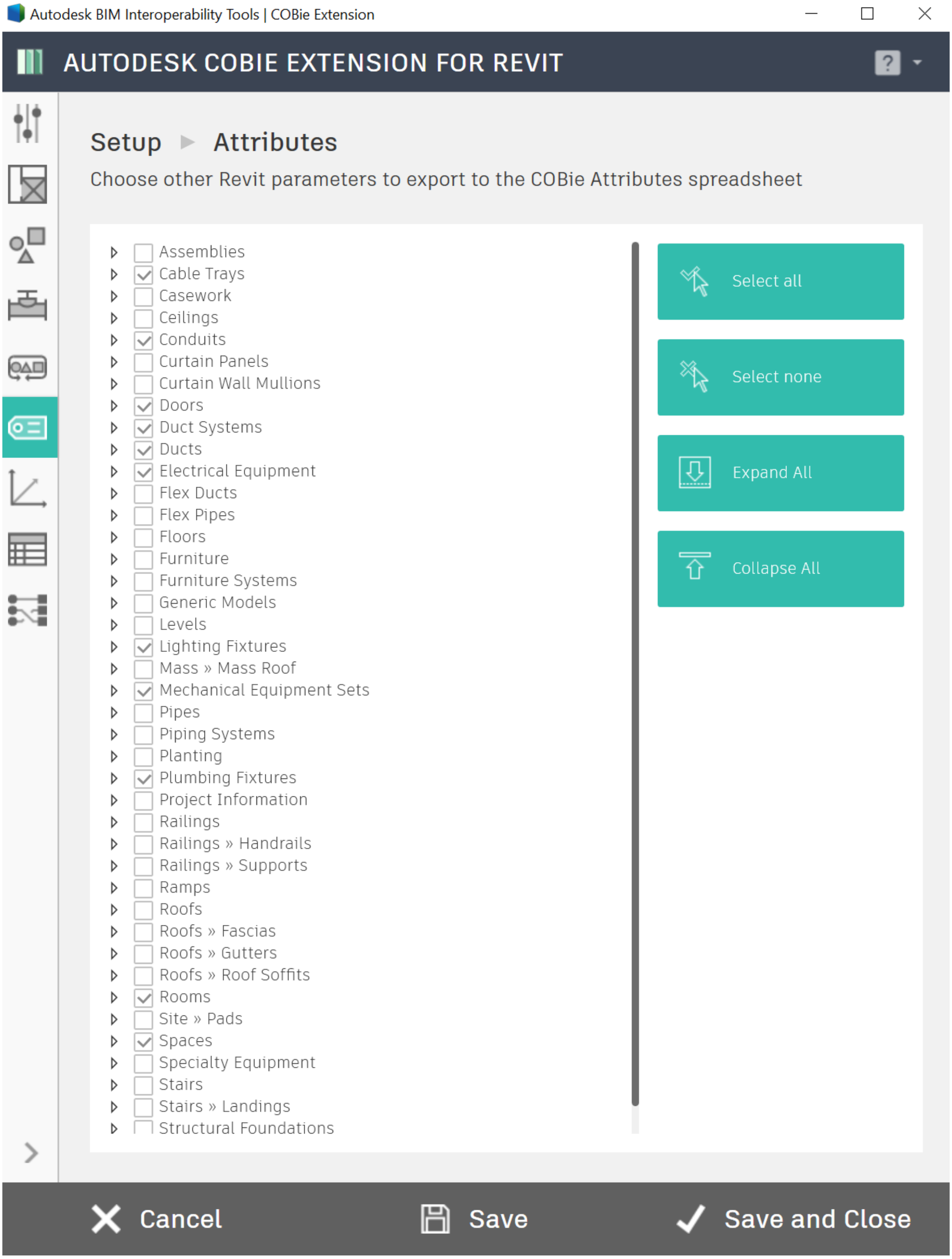
APPENDIX 8E – SETUP–COMPONENTS



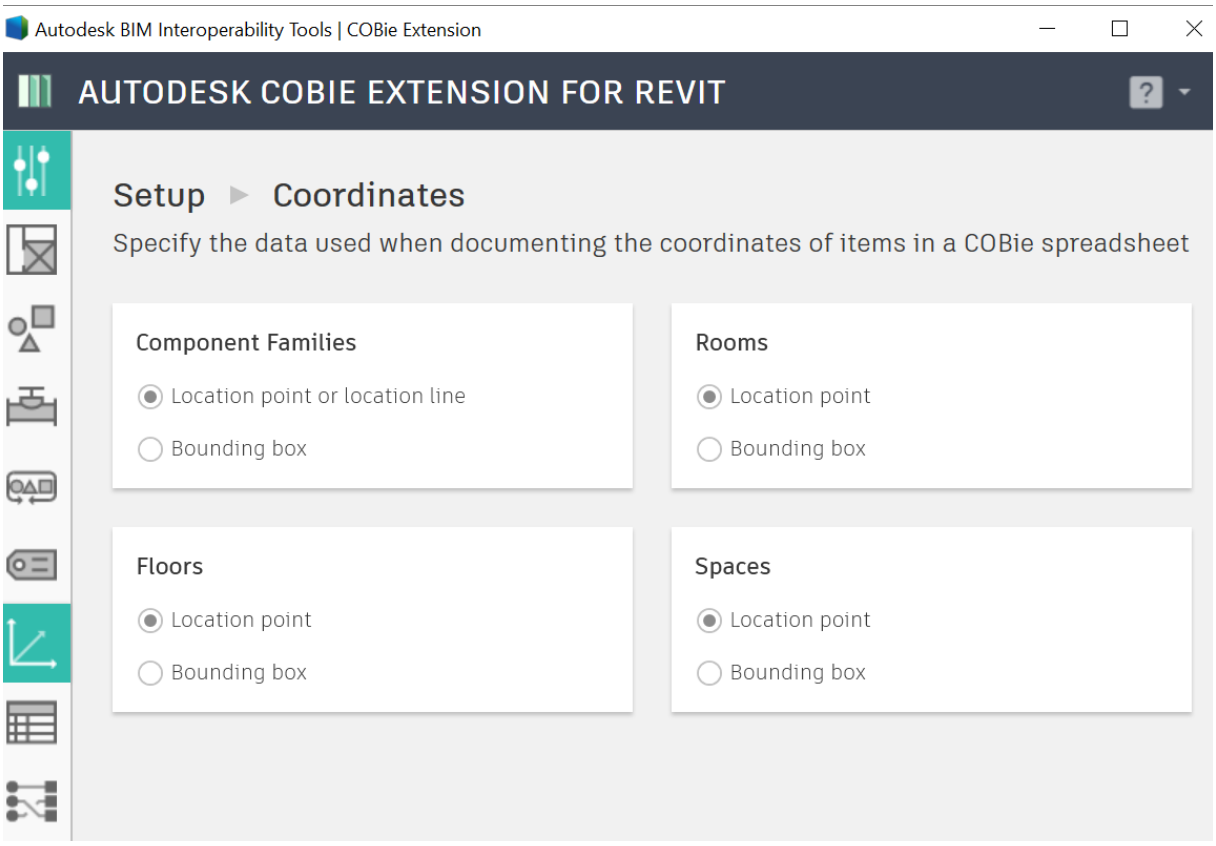
APPENDIX 8F – SETUP–SYSTEMS



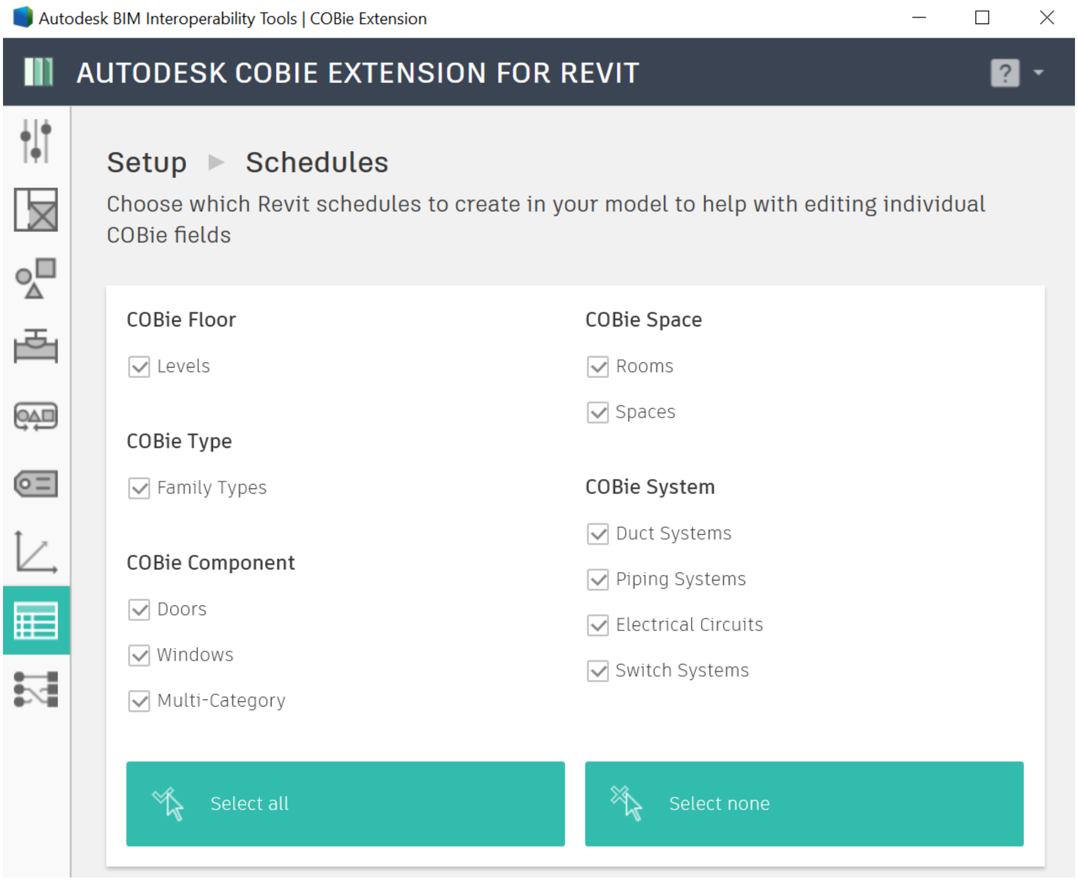
APPENDIX 8G – SETUP–ATTRIBUTES



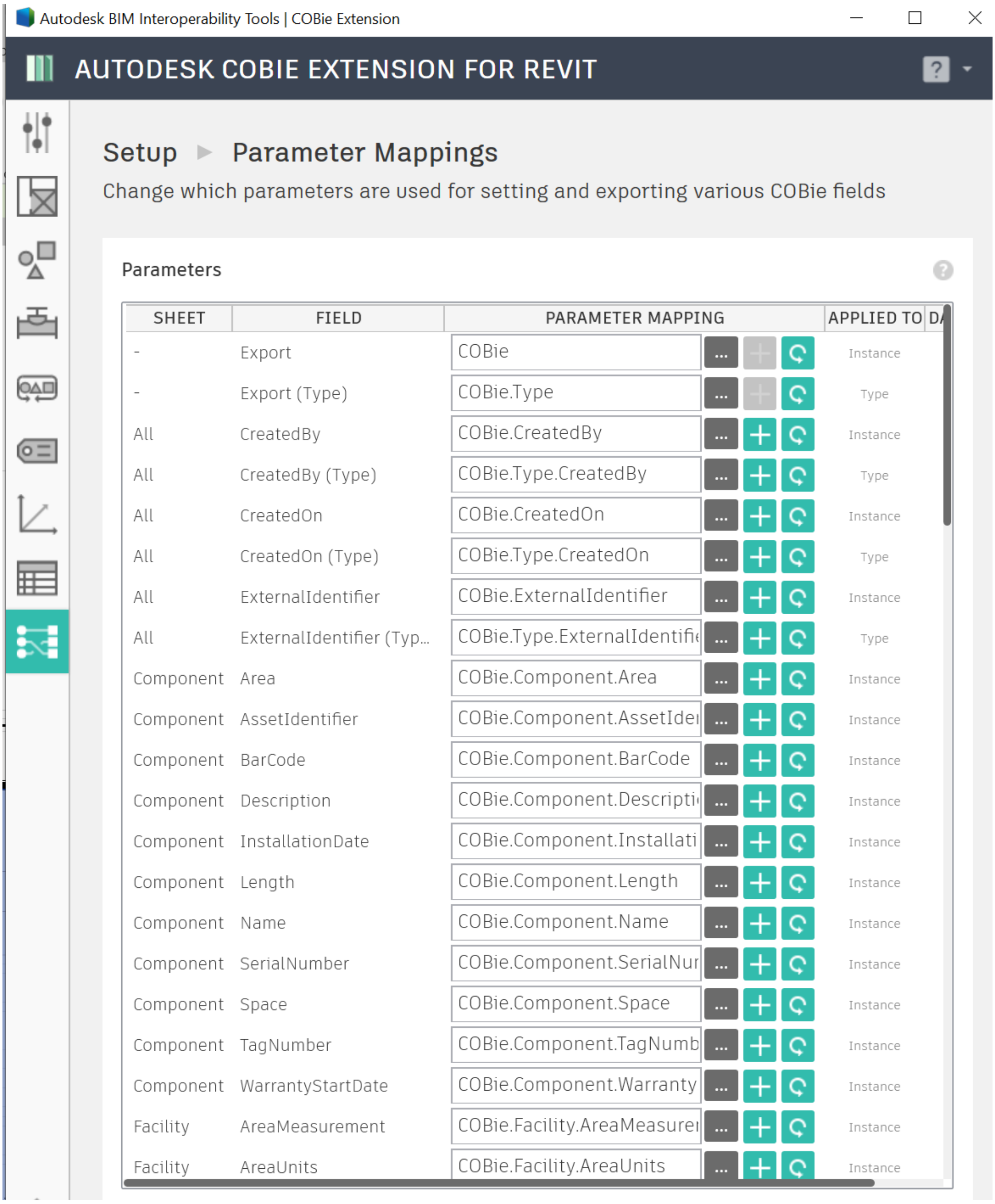
APPENDIX 8H – SETUP–COORDINATES



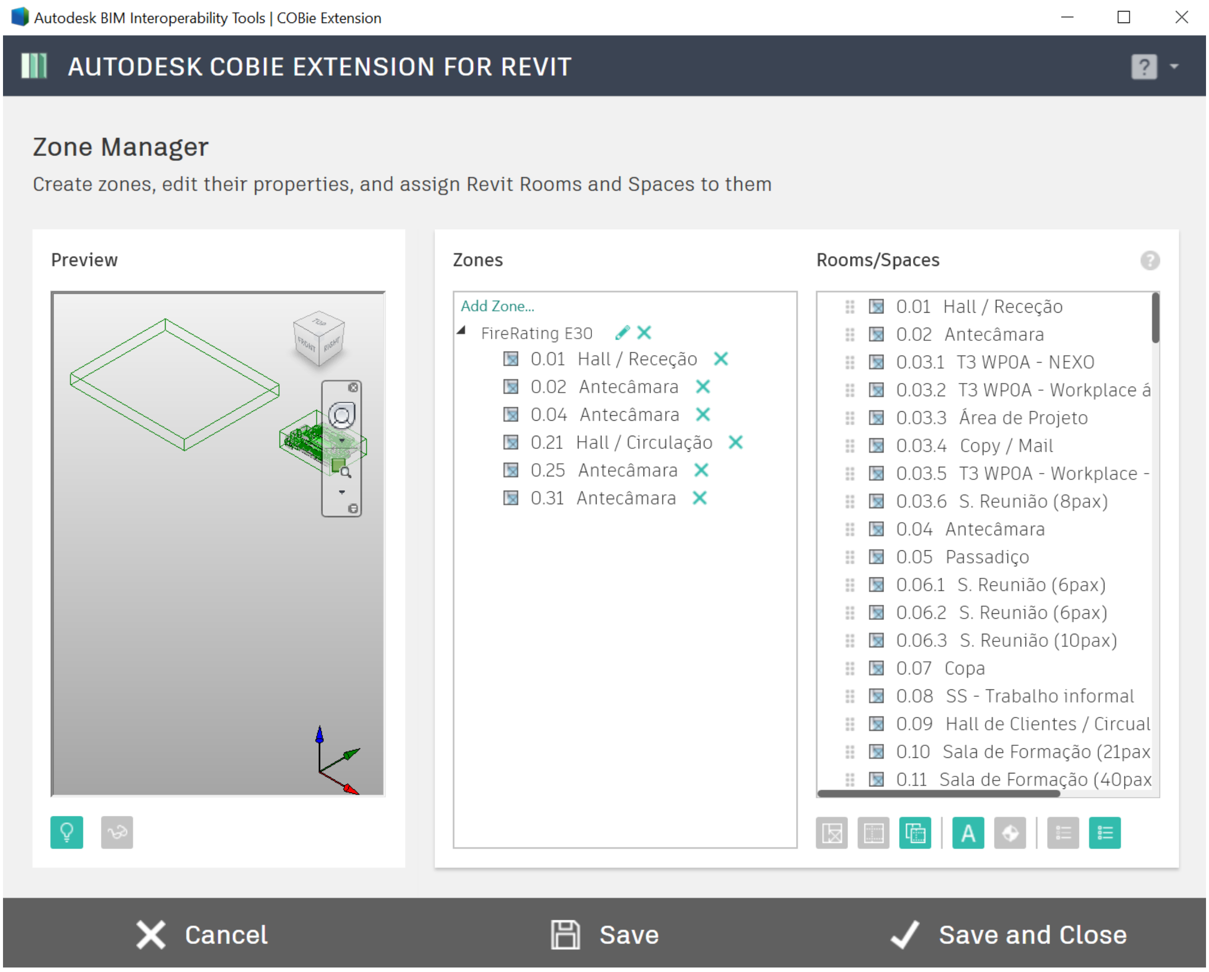
APPENDIX 8J – SETUP–SCHEDULES



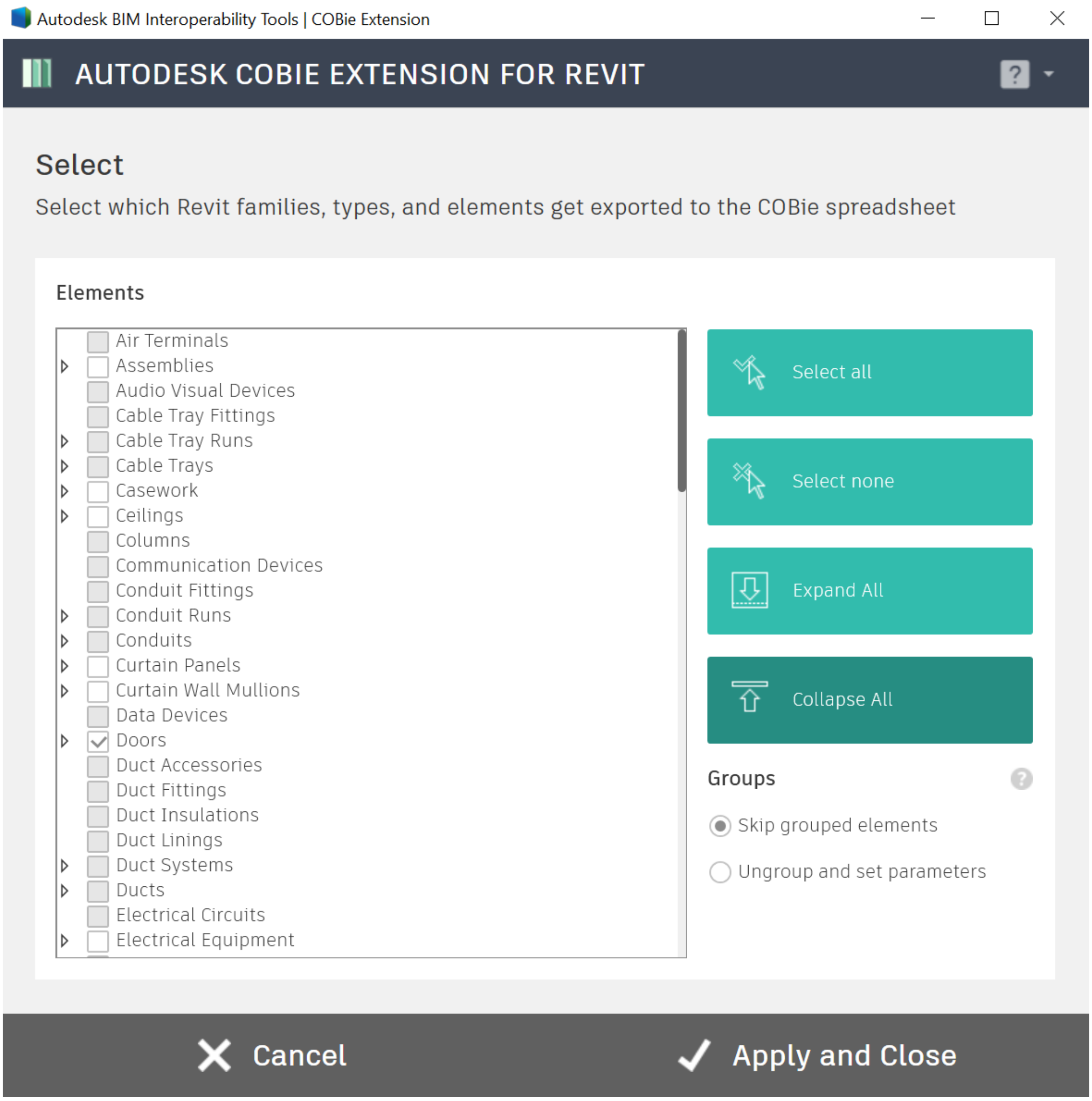
APPENDIX 8K – SETUP–SCHEDULES



APPENDIX 8L– SETUP–ZONES



APPENDIX 8M– SETUP FAMILIES



APPENDIX 9– TABLES GENERATED INSIDE PLANERLY PLATFORM TO SET INFORMATION REQUIREMENTS AND EXAMPLES

2.3.1 -- COBie Requirements - Contact • Saved 3 hours ago IN PROGRESS

CONTACT SHEET

COBie	Description	Example
Email	Author's Email	fl@limsen.com
CreatedBy	automatically mapped from **Email**	
Category	Classification Code : Classification Title	34-55 14 11: Consultant
Company	Company Name	Limsen
Phone	Numeric	+3519xxxxxxxx
External Fields	automatically filled by Revit	
Department	3 letter code assigned in BEP	BIM
Organization Code	3 letter code assigned in BEP	BIM

2.3.2 -- COBie Requirements - Facility • Saved 3 hours ago IN PROGRESS

FACILITY SHEET

COBie	Description	Example
Name	Project Name	NBC Campus
CreatedBy	Choose from the created Contacts	Email
CreatedOn	Date	YYYY-MM-DD
Category	Classification Code : Classification Title	
Project Name	Purpose	Headquarters Office
SiteName	Location	Oeiras
LinearUnits	automatically mapped from the chosen in BIM Interoperability Tools	-
AreaUnits	automatically mapped from the chosen in BIM Interoperability Tools	-
VolumeUnits	automatically mapped from the chosen in BIM Interoperability Tools	-
CurrencyUnit	automatically mapped from the chosen in BIM Interoperability Tools	-
AreaMeasurement	automatically mapped from the chosen in BIM Interoperability Tools unless other is defined	-
External Fields	automatically filled by Revit	

2.3.3 -- ▾ COBie Requirements - Floor • *Saved 2 hours ago* IN PROGRESS ▾

FLOOR SHEET

COBie	Description	Example
Name	Level Name	T3_L3
CreatedBy	Choose from the created Contacts	Email
CreatedOn	Date	YYYY-MM-DD
Category	3 possible options: Roof, Floor, Site	Roof
External Fields	automatically filled by Revit	
Elevation	automatically mapped from Revit Level Elevation	

2.3.4 -- ▾ COBie Requirements - Space IN PROGRESS ▾

SPACE SHEET

COBie	Description	Example
Name	Room Number	001
Category	Classification Code: Classification Title	13-25 13 13 : Entry Lobby
FloorName	automatically mapped from Revit Level Name	T3_L0
Description	Room Name	Hall/Reception
External Fields	automatically filled by Revit	
RoomTag	Concat Room Number_Room Name	001_Hall/Reception
NetArea	Area, no units	143

2.3.5 -- ▾ COBie Requirements - Zone IN PROGRESS ▾

ZONE SHEET

COBie	Description	Example
Name	according to BEP	FireRatingE30
CreatedBy	Choose from the created Contacts	Email
CreatedOn	Date	YYYY-MM-DD
Category	BIM Interoperability Tools	Fire Alarm Zone
Space Names	automatically mapped from Revit according with what defined in BIM Interoperability Tools	Hall/Reception, Circulation, Antechamber

2.3.6 -- COBie Requirements - Type • Saved an hour ago IN PROGRESS

TYPE SHEET

COBie	Description	Example
Name	Tag - Type parameter - TypeMark, Assembly Code, Keynote, Shared Parameter	FCU
CreatedBy	Choose from the created Contacts	Email
CreatedOn	Date	YYYY-MM-DD
Category	Classification Code : Classification Title	21-04 30 30 10: Central Cooling
Description	Type Name or Type Description	Fan Coil Unit
AssetType	Choose from 2 values: Fixed or Moveable	Fixed
Manufacturer	Designation	Daikin
ModelNumber	Designation	
WarrantyGuarantorParts	email, contact	commercial@daikin.com
WarrantyDurationParts	numeric	3FXSQ-A
WarrantyDurationLabor	responsible entity contact, email, website	commercial@daikin.com
WarrantyDurationLabor	responsible entity contact, email, website	commercial@daikin.com
WarrantyDurationUnit	time description (year, month, week)	year
External Fields	automatically filled by Revit	
DurationUnits	time description (year, month, week)	year
Nominal Dimensions	meters	0.90
ModelReference	product commercial designation	FXSQ-A
Shape	solids	rectangular
Colour	text	grey
Finish	text	stained
Material	text	stainless steel
Constitutents	parts that need maintenance, text	filters
Features	product URL	https://www.daikin.pt/pt_pt/products/fxsq-a.html

2.3.8 -- COBie Requirements -System IN PROGRESS

SYSTEM SHEET

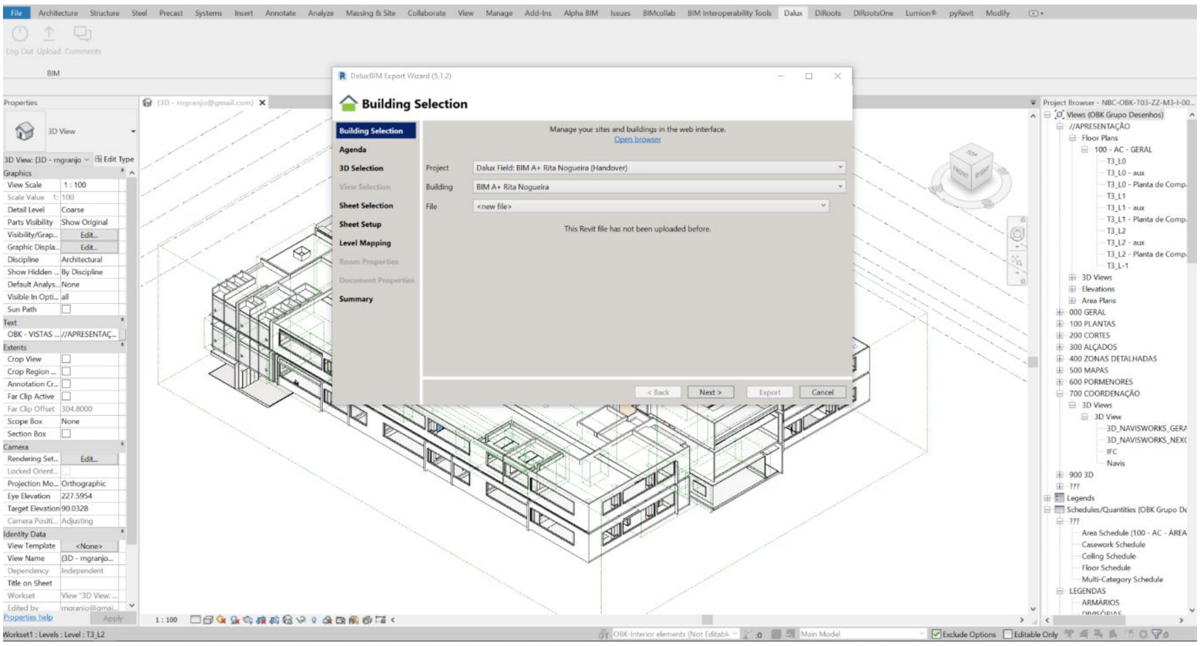
COBie	Description	Example
Name	System Name, according to BEP naming convention	RET.49
CreatedBy	Choose from the created Contacts	Email
CreatedOn	Date	YYYY-MM-DD
Category	Classification Code : Classification Title	21-04 30 30 10: Central Cooling
TypeName	automatically mapped from **TypeName** (defined in Type sheet)	FCU
Space	automatically mapped from **SpaceName** (recognized from Revit)	001
Description	System Classification	Supply Air
External Fields	automatically filled by Revit	
WarrantyStartDate	date	YYYY-MM-DD

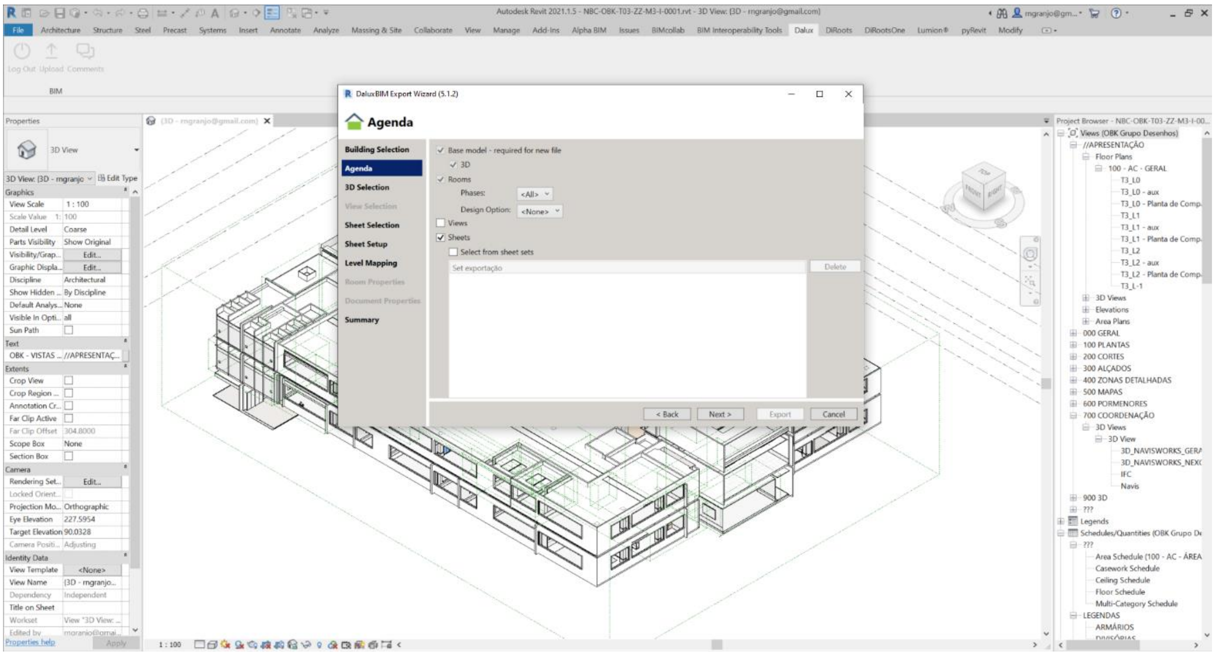
2.3.7 -- COBie Requirements - Component IN PROGRESS

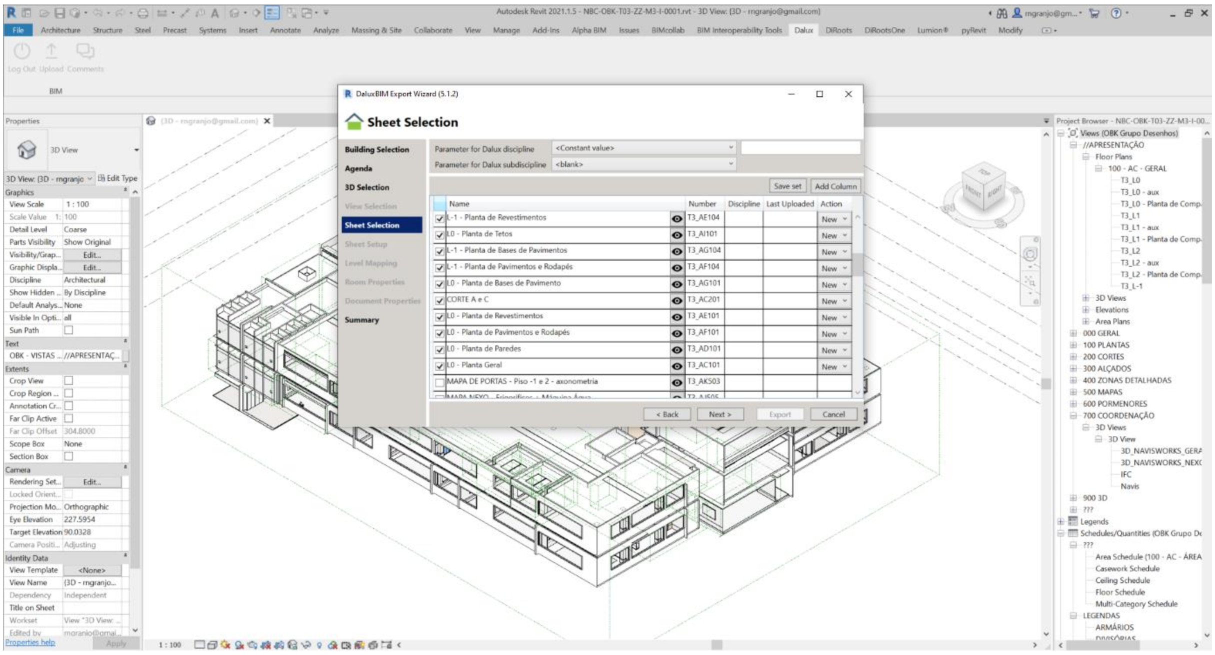
COMPONENT SHEET

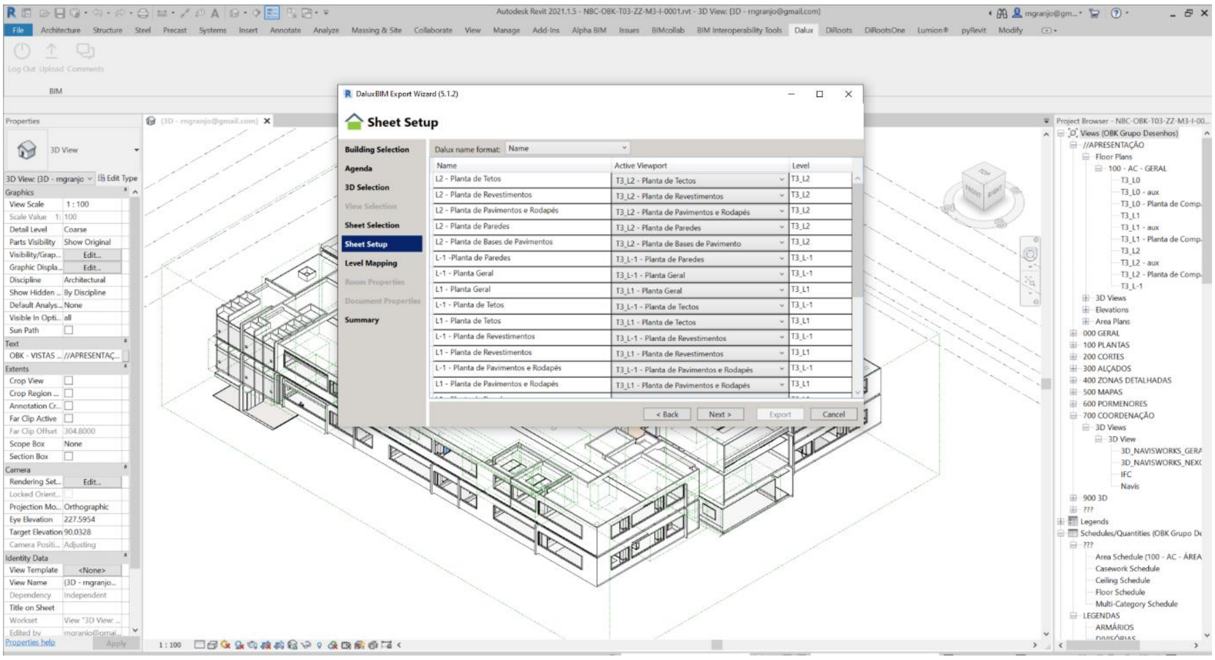
COBie	Description	Example
Name	Tag - Instance parameter - Mark, Shared Parameter	FCU.01
CreatedBy	Choose from the created Contacts	Email
CreatedOn	Date	YYYY-MM-DD
TypeName	automatically mapped from **TypeName** (defined in Type sheet)	FCU
Space	automatically mapped from **SpaceName** (recognized from Revit)	001
Description	Concat Mark_Type Name or Type Description	FCU.01_Fan Coil Unit
External Fields	automatically filled by Revit	
WarrantyStartDate	date	YYYY-MM-DD

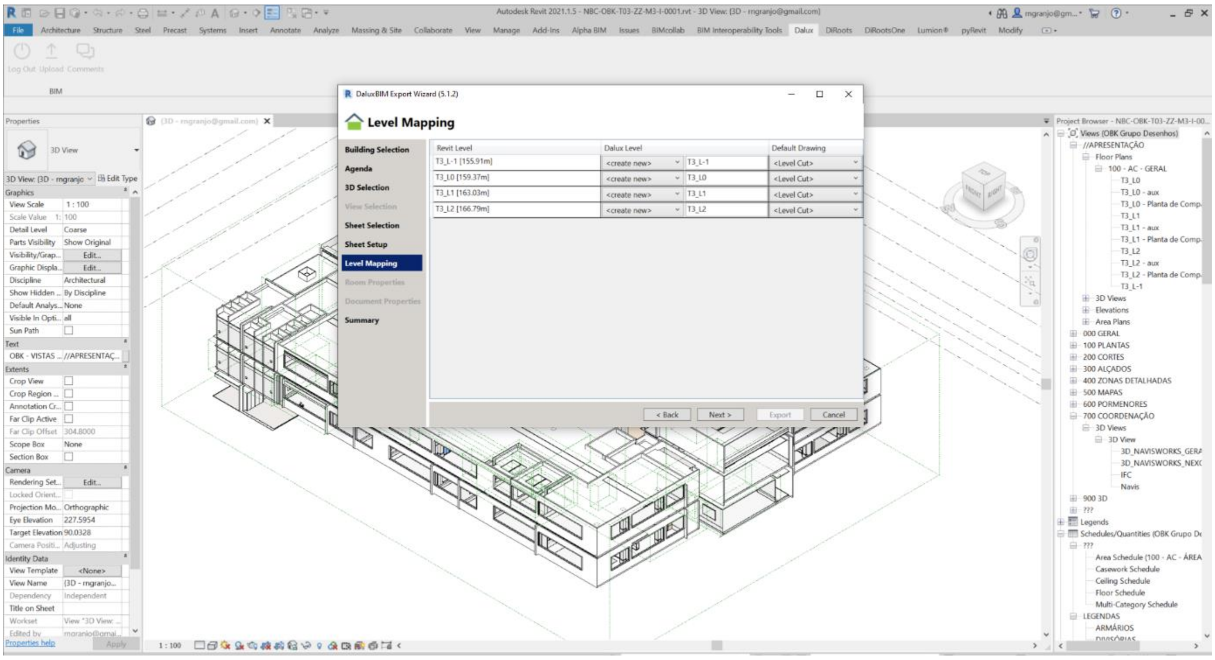
APPENDIX 10: REVIT TO DALUX UPLOAD










DaluxBIM Export Wizard (5.1.2)
Level Mapping
Building Selection
Agenda
3D Selection
View Selection
Sheet Selection
Sheet Setup
Level Mapping
Room Properties
Document Properties
Summary
Revit Level
Dalux Level
Default Drawing
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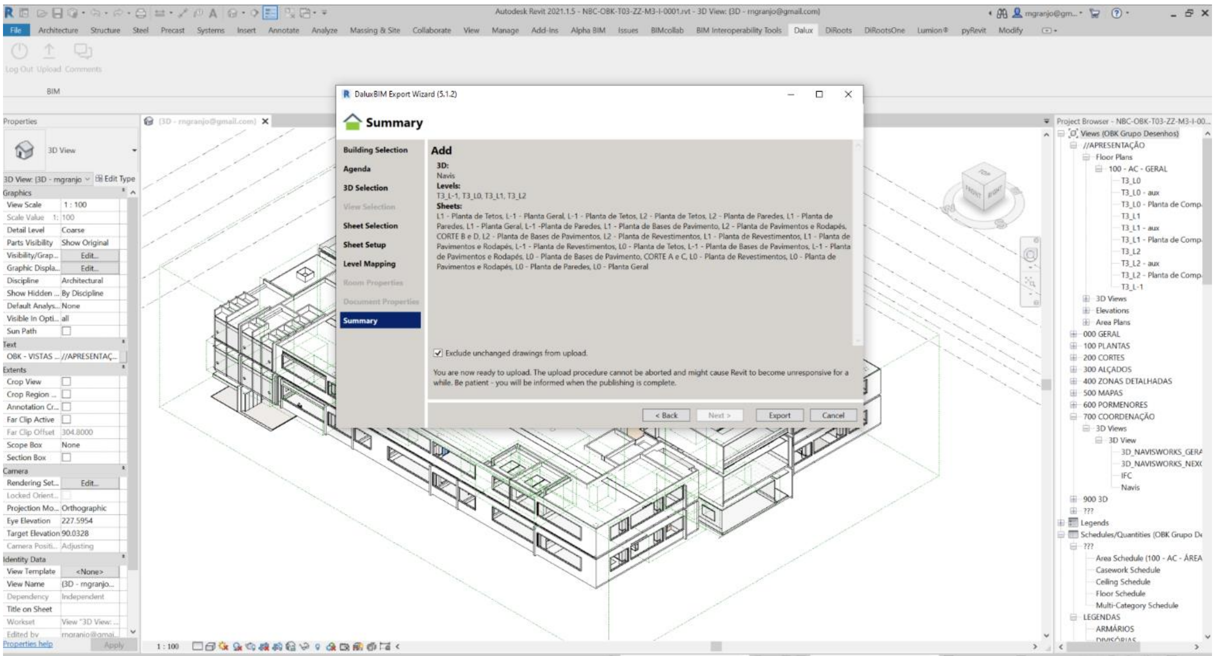
Export
Cancel


DaluxBIM Export Wizard (5.1.2)
Summary
Add
Exclude unchanged drawings from upload.
You are now ready to upload. The upload procedure cannot be aborted and might cause Revit to become unresponsive for a while. Be patient - you will be informed when the publishing is complete.
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Cancel