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Developing a BIM-Based Framework for a Prefabrication Building Company

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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.

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RESUMO

Esta dissertação propõe uma metodologia baseada em BIM para apoiar as pequenas e médias empresas (PME) do setor da construção pré-fabricada. A metodologia procura normalizar fluxos de trabalho de modo a melhorar a eficiência no projeto, planeamento e gestão, em conformidade com as diretrizes da norma ISO 19650. Os seus principais componentes incluem um mapa de processos redesenhado, um protótipo de objeto paramétrico de parede, um Plano de Execução BIM (BEP), Requisitos de Troca de Informação (EIR) e procedimentos de validação de modelos que incorporam o Nível de Necessidade de Informação, as Especificações de Entrega de Informação (IDS) e estratégias de deteção de conflitos. A metodologia foi desenvolvida em colaboração com uma empresa de referência no Brasil e validada através de um projeto-piloto. Os resultados indicam que metodologias baseadas em BIM podem melhorar substancialmente a eficiência, a coordenação e a inovação no setor da construção pré-fabricada. Ao promover práticas normalizadas, estas metodologias permitem ganhos de produtividade a curto e a longo prazo, oferecendo um caminho escalável para que as PME adotem o BIM de forma mais eficaz.

Palavras-chave: Metodologia Baseada em BIM, ISO 19650, Procedimentos de Validação de Modelos, Construção Pré-Fabricada, Gestão De Projetos

ABSTRACT

This dissertation proposes a BIM-based framework to support small and medium-sized enterprises (SMEs) in the prefabricated construction industry. The framework seeks to standardize workflows to improve efficiency in design, planning, and project management, in alignment with ISO 19650 guidelines. Its main components comprise a redesigned process map, a prototype parametric wall object, a BIM Execution Plan (BEP), Exchange Information Requirements (EIR), and model validation procedures incorporating the Level of Information Need, Information Delivery Specifications (IDS), and clash detection strategies. The framework was developed in collaboration with a case company in Brazil and validated through a pilot project. The findings indicate that BIM-based frameworks can substantially improve efficiency, coordination, and innovation in the prefabricated construction sector. By promoting standardized practices, such frameworks enable productivity gains in both the short and long term, offering a scalable pathway for SMEs to adopt BIM more effectively.

Keywords: BIM-Based Framework, ISO 19650, Model Validation Procedures, Prefabricated Construction, Project Management

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1. INTRODUCTION

1.1. General Overview

Over the past decades, the Architecture, Engineering, and Construction (AEC) industry has been transformed by digital technologies, spanning from conceptual design to construction, maintenance, and operation. Among these, Building Information Modelling (BIM) has become a pivotal innovation, reshaping collaboration practices and improving project delivery. BIM provides a multidisciplinary methodology that integrates geometric, informational, and management aspects across the entire project lifecycle (Sacks et al., 2018).

In parallel, prefabricated construction systems have gained momentum as industrialized solutions to long-standing industry challenges such as productivity, cost predictability, safety, and material waste. By manufacturing components in controlled environments and assembling them on-site, prefabrication shortens timelines, improves quality control, and reduces waste. However, its success depends on skilled labour and effective integration into construction processes (Smith, 2010).

Despite their natural complementarity, integrating BIM and prefabrication remains complex, especially for small and medium-sized enterprises (SMEs). Large firms often have the resources and expertise to adopt BIM, while SMEs face barriers such as limited budgets, lack of specialized professionals, and organizational resistance (Yoo, 2019). Consequently, many SMEs continue to rely on conventional and fragmented workflows.

Although research has explored BIM adoption in SMEs (Kouch et al., 2018; Babatunde, 2022; Li et al., 2019), most studies focus on conventional construction and treat SMEs as a uniform category. This overlooks the specific demands of prefabrication, which requires high digital precision and interoperability, areas where BIM could be transformative. There is a study that highlighted recurring issues faced by SMEs in prefabrication, such as poor collaboration, weak information management, and limited lifecycle integration (Yoo, 2019; Mahmoud, 2022). Yet, these insights remain fragmented, with little effort toward comprehensive BIM-based frameworks.

This dissertation addresses this gap by developing a BIM-based framework for a Brazilian prefabricated construction SME, aligned with ISO 19650 standards and validated through a pilot project. Despite its experience supplying residential and commercial elements, the company faces common SME challenges: non-standardized workflows, inconsistent information management, and limited cross-department collaboration. Tackling these issues can help unlock BIM’s potential to enhance efficiency and competitiveness.

1.2. Objectives

The general objective of this research is to develop a BIM-based framework tailored to SMEs in the prefabricated construction industry, with the purpose of improving design and planning processes, project management efficiency, and collaboration across disciplines. The research objectives include the application of ISO 19650 guidelines and the incorporation of standardized data management tools such as Level of Information Need, Information Delivery Specification (IDS), and a classification system, as well as a prototype parametric object to support cost estimation.

1.3. Methods of Research

The methodology comprised the following key steps:

1. **Process Mapping**: The existing construction and design workflows were analysed and redesigned to integrate BIM principles, ensuring alignment with ISO 19650 standards.

2. **BIM Execution Plan (BEP) and Exchange Information Requirements (EIR):** A BEP was defined to guide project execution, and a EIR was prepared for collaboration with an MEP subcontractor. These documents established clear responsibilities, information exchange protocols, and required levels of detail.

3. **Parametric Object Development:** A prototype parametric wall object was developed to support cost estimation using GDL, the functional programming language of ArchiCAD for defining architectural objects.

4. **Model Validation:** The BIM model was validated using Clash Detection, Levels of Information Need, and Information Delivery Specifications (IDS) to ensure consistency, accuracy, and completeness of information throughout the project lifecycle.

5. **Pilot Project Simulation:** The proposed framework was tested through a simulated pilot project to demonstrate its practical application and evaluate its potential benefits for prefabricated construction processes.

This methodology contributes academically by addressing a gap in the literature on BIM adoption strategies for SMEs in prefabrication. Practically, it provides a real-case application for structuring company processes and enhancing collaboration, efficiency, and information management through BIM.

1.4. Structure of the Dissertation

This dissertation is structured into six chapters, each addressing a different dimension of the research:

- **Chapter 1 - Introduction:** Presents the research context, problem statement, objectives, key topics and methodology.

- **Chapter 2 - BIM for Prefabricated Construction:** Provides the theoretical background, discussing the history of prefabrication, BIM's role in SMEs, design challenges, contractual aspects, and key elements of BIM implementation.

- **Chapter 3 - Case Study: Company Analysis:** Introduces the case company, maps current practices, and identifies opportunities for adopting ISO 19650.

- **Chapter 4 - Proposed BIM-Based Improvements and Implementation Strategy:** Details the framework developed for the company, including redesigned process maps, BEP, EIR, validation procedures, and parametric object creation.

- **Chapter 5 - Pilot Project for BIM Implementation:** Demonstrates the framework's practical application, testing workflows and model validation.

- **Chapter 6 - Conclusions and Future Work:** Summarizes findings, highlights contributions, and provides recommendations for future research and implementation.

The Annexes include supporting documentation such as AS-IS and TO-BE process maps, maturity assessments, BEP, EIR, naming conventions, and, Level of Information Need definition.

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2. BIM FOR PREFABRICATED CONSTRUCTION

2.1. A Brief History of Prefabricated Construction

Prefabricated construction is often associated with contemporary techniques that aim to accelerate building processes in response to today's fast-paced world, where productivity, cost efficiency, and time savings are priorities. However, the concept of prefabrication is not new; its roots lie in the practice of manufacturing building components off-site for later assembly, a method evident as early as the use of quarried and shaped stone blocks for monumental structures such as the Egyptian pyramids and Roman aqueducts. Over time, this practice evolved, and the modern notion of prefabrication emerged as a systematic industrial process created to drive technological innovation, industrialization, and socio-economic transformation (Smith, 2010).

During the 19th century, the European Industrial Revolution marked a significant turning point for prefabricated construction. The convergence of new mechanical production systems with advancements in transportation networks facilitated the development of standardized and reproducible building components (Smith, 2010). The techniques demonstrated a significant potential for modular design and mass production in architecture. Beyond remarkable buildings, the prefabrication also proved great advantages in functional applications, including military barracks, workers' housing, and emergency shelters (Santi, 2017).

In the 20th century, prefabrication was adopted on a much larger scale, particularly in European countries engaged in post-war reconstruction, where it enabled the rapid rebuilding of devastated urban areas. For instance, large-panel concrete housing blocks were developed in Ukraine (Figure 1). These projects demonstrated the efficiency and speed of prefabrication, although they were often criticized for their lack of architectural quality and monotonous design (Malaia, 2020).

Figure 1 - Prefabricated panel construction in 1960, in Ukraine (Malaia, 2020)

Today, the association between prefabricated buildings and poor design has largely disappeared. Advances in techniques have demonstrated that prefabricated solutions can be creative, adaptable, and expressive, contributing meaningfully to architectural identity. The construction market now offers a wide variety of materials and systems that can be tailored to client requirements as well as climatic and environmental conditions (Adeyemi et al.,2024). Prefabrication has also proven its versatility, being applied across different scales of construction, from skyscrapers (Figure 2 (a)), to medium-scale developments (Figure 2 (b)), including both single and multi-family residences (Figure 2(c)).

(a) (b) (c)

Figure 2 – prefabrication developments – (a) Zalmhaven Toren prefab towers, Rotterdam (Dam & Partners Architecten, 2022), (b) Wohnregal Apartments and Studios / FAR frohn&rojas, Berlin (David von Becker, 2019), (c) SUMMARY | FG+SG, Portugal (Fernando Guerra, 2020)

Today, several countries stand out as global leaders in prefabricated construction. Sweden is widely regarded as a pioneer in timber-based prefabrication and sustainable practices. Japan is recognized for its high-quality production standards, integration of prefabrication into building codes, and capacity for mass production. China has significantly increased its investment in research and large-scale adoption of prefabricated methods in recent years. The United States also plays an important role as the major exporter and a contributor to international research collaborations. In addition, countries such as Singapore, Germany, and Canada have gained recognition for their extensive use of off-site manufacturing and integration of prefabrication into their construction industries (McKinsey & Company, 2019).

In parallel with advances in construction techniques and factory-produced building systems, the integration of Building Information Modelling (BIM) has played a significant role in enhancing information management, design coordination, and production efficiency. This alliance between construction techniques and information management has transformed prefabrication into a high-precision, design-driven, and sustainable construction method, enabling it to effectively address the complex demands of contemporary architecture and urban development (Li et al., 2019).

2.2. The Role of BIM in SME Prefabrication

According to the Annual Report on European SMEs 2022/2023, small and medium-sized enterprises (SMEs) account for up to 95% of firms in construction, architecture, and civil engineering across Europe (European Commission, 2023). Similar patterns persist globally: in Brazil, the SMEs constitute approximately 93.7% of all legally registered companies, and across the broader economy

(OECD, 2020). Given these firms' influence, especially as contractors and industry drivers, their operational practices are critically important to the construction sector worldwide.

In this scenario, one of the most significant contributions of BIM to SMEs of prefabrication systems is its ability to facilitate accurate, coordinated design and enable the creation of detailed digital models even with relatively small work teams (Antwi-Afari et al., 2018). This capability reduces errors, rework, and traceability issues while enhancing collaboration among designers, engineers, manufacturers, and subcontractors. Despite the smaller scale of SMEs, the number of stakeholders and the complexity of multidisciplinary tasks remain high, making BIM an essential tool for coordination and integration (Sacks, 2018).

However, the adoption of BIM among SMEs remains inconsistent. Key barriers include high initial implementation costs, organizational resistance to change, limited availability of skilled personnel, and challenges related to interoperability across platforms. To address this issue, governments and industry associations are increasingly encouraging BIM adoption through policy mandates, training programs, and the development of open standards. These initiatives are expected to significantly support SMEs in overcoming existing barriers and in realizing the benefits of BIM in the near future (Chmeit, 2024).

2.3. Challenges in Architecture and Prefabrication

The integration of prefabricated construction into architectural design offers both significant opportunities and notable challenges. While prefabrication can enhance efficiency, quality, and sustainability, it also requires adaptations in traditional architectural workflows, design development, and collaborative processes (Adeyemi et al., 2024). Within this context, several critical challenges emerge that must be addressed to deliver the potential of prefabricated construction.

2.3.1. Adapting Conventional Architectural Designs for Prefabrication

Traditionally, architectural design emphasizes unique solutions and expressive design languages, while prefabrication requires modularity, repeatability, and precise coordination. This divergence can create challenges for architects attempting to harmonize creative freedom with the constraints of prefabricated production (Zhang, 2024).

When prefabrication requirements are integrated into the conceptual design from the beginning, the alignment between design language and construction system techniques becomes more unified. However, a common practice in the construction industry is to contract architects to develop designs without fully considering structural or prefabrication implications. Consequently, construction companies must make significant adaptations to implement prefabricated systems. This misalignment often necessitates substantial modifications for both architects and construction firms (Eloranta, 2021).

Furthermore, the transition from traditional to prefabricated design demands early-stage integration of structural and manufacturing considerations. Architects accustomed to linear design workflows may struggle to adapt to the iterative, collaborative processes that prefabrication requires. Without early coordination with engineers and manufacturers, projects may experience inefficiencies, increased costs, or even infeasibility (Eloranta, 2021).

To address these challenges, the construction industry has demonstrated the efficiency of developing more flexible, adaptable design strategies that balance architectural language with prefabricated construction systems. Such approaches facilitate collaboration, reduce conflicts, and optimize both design creativity and construction feasibility (Adeyemi et al., 2024).

2.3.2. Prefabricated Structures Modelling

Prefabricated elements (Figure 3) often demand a detail model, including tolerances, connections, and logistics requirements, adding complexity in the design phase and placing time-consuming documentation tasks carried by the project delivery team. BIM platforms, while structured to deliver precision, frequently outcome data-heavy models that hinder efficiency. Consequently, many firms explore multiple BIM tools and tool combinations until they identify a configuration that meets their precision and delivery needs (Schreyer, 2018).

The success of prefabricated construction depends on optimizing the workflow, from design to on-site assembly, which requires standardized processes, effective information management tools, and intensive collaboration before the construction phase starts. Under such conditions, the assembly itself can be completed within a few days, while the collaborative design team must remain highly attentive to deadlines and ensure that all project requirements are fully addressed. During the documentation stage, unexpected alterations can significantly compromise both efficiency and schedule compliance, creating additional challenges in meeting project deadlines (Wang, 2018).

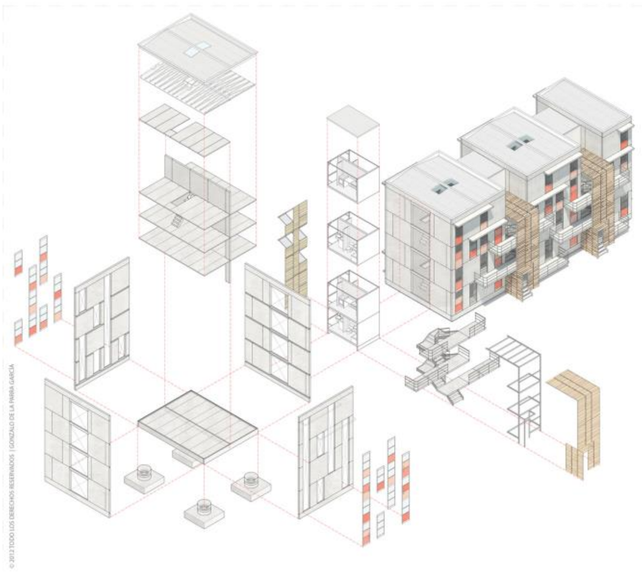

Figure 3 – Example of prefabricated construction in BIM-model (Gonzalo De La Parra García, 2018)

2.3.3. Tools for Parametric Modelling

Parametric modelling is increasingly gaining prominence within architectural design and construction due to the continuous evolution of digital tools resolve modelling challenges. By defining design elements through algorithms and adjustable parameters, architects are able to generate flexible, adaptable models that align with modular and prefabrication requirements. Platforms such as

Grasshopper (2025), Dynamo (2025), ArchiCAD Graphisoft (2025), and Revit Autodesk (2025), especially the use of parametric object classes, stand as key BIM tools facilitating this capability (O'Neill, 2020).

However, these platforms often rely on visual or text-based programming environments, which can present a significant barrier to professionals who lack computational fluency. A recent systematic review by Seghier et al. (2024) highlights visual programming's growing role within computational BIM. Yet notes that such approaches demand specialized knowledge in algorithmic thinking and scripting, which may not be widely accessible across AEC professionals.

Although parametric design holds strong potential to bridge the gap between architectural creativity and industrialized productivity, effective implementation relies on the availability of team skills and resources. SMEs in the construction sector are particularly challenged because they often lack robust IT support teams capable of developing or adapting parametric object classes tailored to prefabrication needs. A review by Vidalakis (2020) focusing on BIM adoption in SMEs underscores this issue, noting that financial limitations, insufficient training, and human resource constraints pose significant obstacles.

2.4. Contractual Relationships in Prefabrication Construction

Traditionally, construction contracts have been dominated by the design-bid-build (DBB) format. While this approach establishes clear boundaries between design and construction responsibilities, it often proves inadequate for prefabricated construction, where design, manufacturing, logistics, and on-site assembly are highly interdependent. In DBB contracts, the late involvement of contractors and fabricators may lead to design inconsistencies, coordination failures, and increased conflicts, since prefabrication demands early integration across disciplines (Lu et al., 2018).

To address these contract gaps, prefabricated construction companies increasingly adopt collaborative contractual models such as Integrated Project Delivery (IPD), design-build (DB), and early contractor involvement (ECI). These formats promote multidisciplinary collaboration from the earliest project stages, aligning design choices with manufacturing factors, transportation, and on-site installation strategies (El Asmar et al., 2013). Within this framework, BIM acts as a facilitator and mediator to establish roles, deliverables, and responsibilities transparently shared and monitored (Alotaibi, 2024).

However, the use of BIM in collaborative contracts introduces new challenges. Since BIM models are shared and co-developed, disputes may arise regarding data ownership, intellectual property, and responsibility for design or coordination errors. International standards such as ISO 19650 provide guidance on structuring these relationships, particularly through tools like the Exchange Information Requirements (EIR) and the BIM Execution Plan (BEP), which clarify roles, data responsibilities, and accountability (ISO, 2018).

Another important contractual consideration for prefabrication is supply chain management. Contracts must explicitly address just-in-time delivery, off-site production schedules, and logistics coordination. Any disruption in the manufacturing process can have cascading effects on project timelines, cost, and quality. As a result, risk allocation mechanisms become central to prefabrication contracts, ensuring that delays or defects in one stage do not disproportionately penalize other parties. Emerging digital-enabled collaborative contracts, often supported by BIM-integrated platforms, seek to build trust and transparency among stakeholders while providing flexible frameworks to handle these interdependencies (Jelodar et al., 2017).

In summary, while traditional DBB contracts have historically governed construction projects, prefabricated construction demands contractual innovations that integrate supply chain management, digital collaboration, and early stakeholder involvement. Such frameworks not only reduce conflict but also unlock the productivity and quality gains associated with industrialized construction.

2.5. Key Elements for BIM Implementation

As previously discussed, prefabricated construction relies on the coordination of multiple interdependent factors to achieve efficiency and quality. Similarly, the effective adoption of BIM extends far beyond the deployment of digital tools: it requires structured process management, systematic maturity assessment, and the implementation of well-defined standards to ensure interoperability and reduce fragmentation among project stakeholders (World Economic Forum, 2018). In this regard, the ISO 19650 series establish a global benchmark for information management throughout the entire life cycle of the built environment, promoting consistency, transparency, and collaborative practices (ISO 19650-1:2018).

2.5.1. Process Management

The first concept in a well-structured BIM-based framework is the definition of process management. One widely adopted methodology for process mapping is the Business Process Model and Notation (BPMN), an internationally recognized graphical standard designed to bridge communication between business stakeholders and technical experts (EBSCO,2024). BPMN provides a comprehensive and user-friendly visual language that represents events, activities, and the corresponding actors, while highlighting the interdependencies within enterprise processes. It offers a set of well-defined elements (Figure 4) to model workflows at different levels of complexity, enabling both high-level conceptualization and detailed process execution.

The BPMN diagrams consist of standardized symbols categorized as follows by EBSCO (2024):

1. **Flow Objects -** Represent actions and control points:
    - Events - start, intermediate, or end a process.
    - Activities - task, subprocesses to be performed.
2. **Gateways** - mark decision points:
    - Exclusive (X) - unify the flow to be followed.
    - Inclusive (circle) - bifurcation point in the process.

- Parallel (+) - synchronizes or creates parallel flows
- Complex (*) - used to combine a set of complex connection gateways.

3. **Connecting Objects** - Define flow relationships:
   - Sequence Flows: solid arrows.
   - Message Flows: dashed arrows between pools.
   - Associations: dotted lines linking to artifacts.
4. **Swimlanes** - Visual containers:
   - Pools: represent participants or organizations (stakeholders).
   - Lanes subdivide responsibilities within pools in a process.
5. **Artifacts** - Supplementary information:
   - Data files, Groups, Annotations for clarifications.

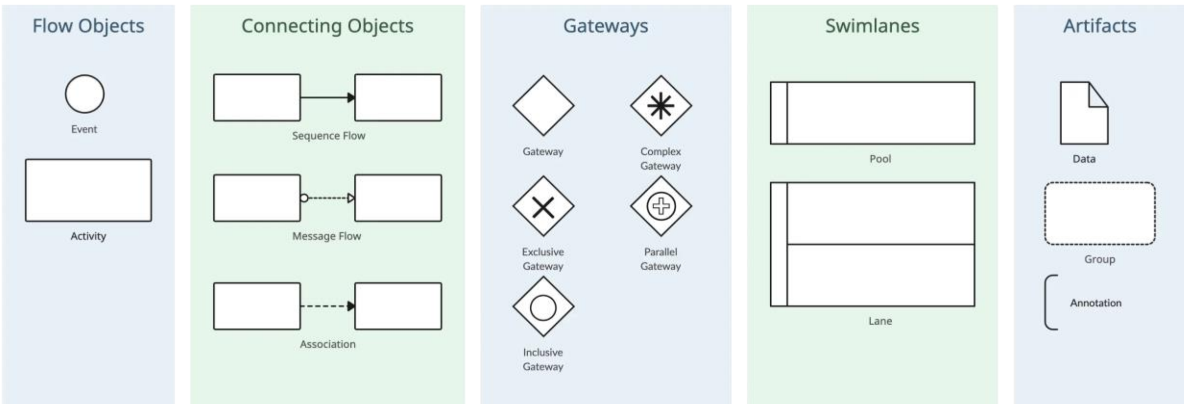

Figure 4 – The Main BPMN Symbols (Creatly, 2024)

2.5.2. Maturity Assessment

Another essential concept for BIM-based frameworks is assessing the company's BIM maturity level. This represents the organization's capability to implement BIM procedures in a consistent and effective manner. One solid maturity matrix model used as a reference is the one developed by BIMe Initiative (BIM Excellence Initiative, 2013). This tool provides a structured framework for evaluating BIM adoption across multiple organizational dimensions, including policies, processes, people, and technology. By identifying current capabilities and gaps, the BIMe Matrix supports companies in defining strategic roadmaps and good practices in order to align their processes with industry standards. Furthermore, the model facilitates a gradual improvement transition, allowing companies to progress from basic BIM procedures to advanced, integrated, and collaborative workflows (BIM Excellence Initiative, 2013).

The BIM Maturity Matrix (BIm³) by BIM Excellence Initiative (2013), consists of five levels (Figure 5), from nascent efforts to optimized integrated practices as follows:

1. **Initial / Ad-hoc -** Low maturity (Numerical Rating 0-19%) - the BIM implementation is isolated and there is no organizational direction. The collaboration is minimal, with no standardized practices.

2. **Defined** - Medium-Low maturity (Numerical Rating 20-39%) - more structured, with documented processes, policies, and explicit management support. Processes are guided by training materials, workflow guides, and clearly stated BIM delivery standards. Collaboration is improving, driven by predefined protocols and mutual trust among stakeholders.

3. **Managed** - Medium maturity (Numerical Rating 40-59%) - the organization has established procedures consistently applied. BIM becomes more predictable and measurable, with performance controls, risk, and costs. Outcomes align more closely with targets, as processes are monitored and adjusted over time.

4. **Integrated** - Medium-High maturity (Numerical Rating 60-79%) BIM capabilities are organizationally embedded, enabling multi-disciplinary collaboration and execution. The workflows across teams are synchronized, and consistent.

5. **Optimized** - High maturity (Numerical Rating 80-100%) - the practices are well defined, continuously improved, and exceed standard expectations. Organizations demonstrate high-level predictability, efficiency, and strategic use of BIM to drive innovation aligned with the organizational objectives. There is a strong focus on excellence, new goal-setting, and progressive process refinement.

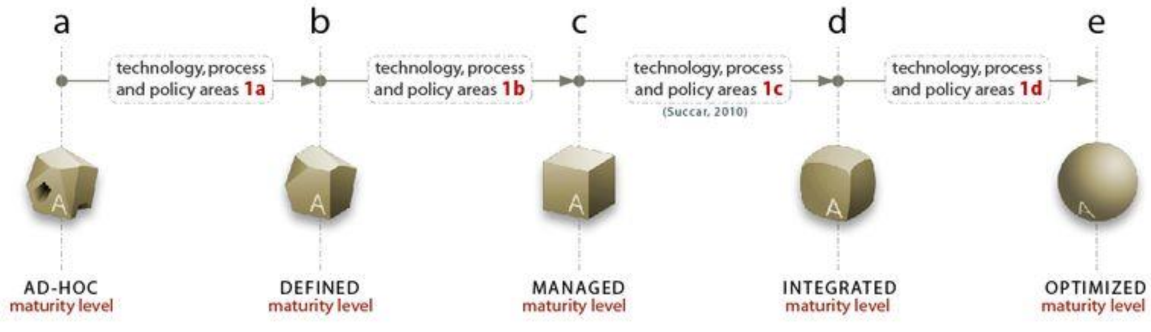

Figure 5 – BIM Excellence Initiative BIM Maturity Levels (BIM Excellence Initiative, 2013)

2.5.3. Exchange Information Requirements (EIR)

The EIR (Exchange Information Requirements) is a client-led document that specifies what information is needed, when, how, and for whom, during the delivery phase of an asset. The ISO 19650 (ISO, 2018) series define the EIR foundation for effective information management at the tendering stage, guiding the delivery team's response via their Pre-BEP and later their contractual BEP, addressing objectives in information exchanges (UK BIM Framework – Guidance Part D, 2021).

The EIR is structured around technical, management, and commercial aspects, and typically includes specifications for software platforms, required levels of detail, collaboration workflows, and data exchange formats. It also integrates high-level information needs derived from Organisational, Asset, and Project Information Requirements (OIR, AIR, PIR) as inputs. The EIR bridges strategic client expectations with BIM delivery standards (UK BIM Framework – Guidance Part D, 2021).

By defining precise criteria, including information standards, production methods, procedure expectations, and response mechanisms, the EIR informs the tendering process and ensures that project information flows are aligned with project objectives. It acts as both a reference point and a contractual enabler: the delivery team responds with a Pre-BEP to demonstrate how they intend to meet these requirements, and post-award, the EIR remains the benchmark for information delivery performance and compliance throughout the project's delivery phase (Figure 06) (UK BIM Framework – Guidance Part D, 2021).

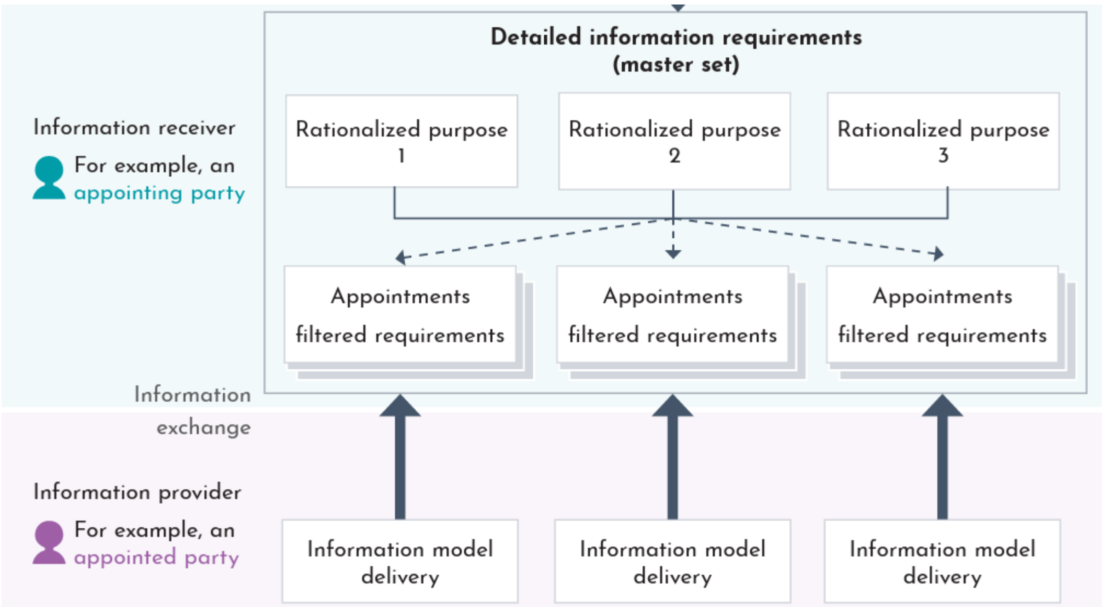

Figure 6 – Breakdown of information requirements for the EIR (UK BIM Framework, 2021)

2.5.4. BIM Execution Plan (BEP)

According to ISO 19650 (ISO, 2018), a BIM Execution Plan (BEP) is a structured plan created by the project team to define how BIM will be managed throughout a project. It establishes the processes, procedures, and responsibilities for producing, sharing, and using information effectively (Figure 7). It ensures that all parties coordinate their information management, comply with client requirements, and follow agreed standards and protocols. The BEP also clarifies BIM roles and responsibilities regarding deliverables and is linked to the Project Information Requirements (PIR) and the Exchange Information Requirements (EIR), serving as a roadmap for project delivering information (ISO 19650-2, 2018).

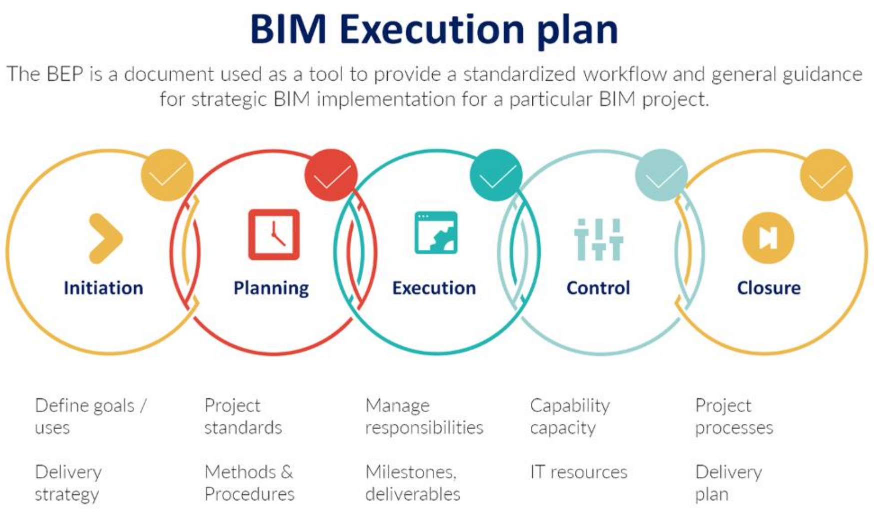

Figure 7 – BIM Execution Plan definition (BIMdesignhub, 2021)

There are two version of BEP: pre-appointment BEP and the Post-appointment BEP (Figure 8). When preparing a Pre-BEP, which is developed during the tender stage (before contract signature), the prospective lead appointed party should consider three possible scenarios. In the first scenario, the appointing party provides a BEP template as a shared resource to support the tender and appointment process. In the second scenario, no template is provided, but the appointing party specifies the content that must be included to meet its evaluation criteria. In the third scenario, the appointing party does not provide any guidance regarding the BEP, and the prospective lead appointed party must respond by preparing a pre-BEP. In turn, the Post-BEP, is the detailed BIM Execution Plan developed after the contract signature, created collaboratively to serve as a practical guide for managing BIM throughout the project lifecycle, in order to ensure the alignment between stakeholders and the agreed methods (ISO 19650-2, 2018).

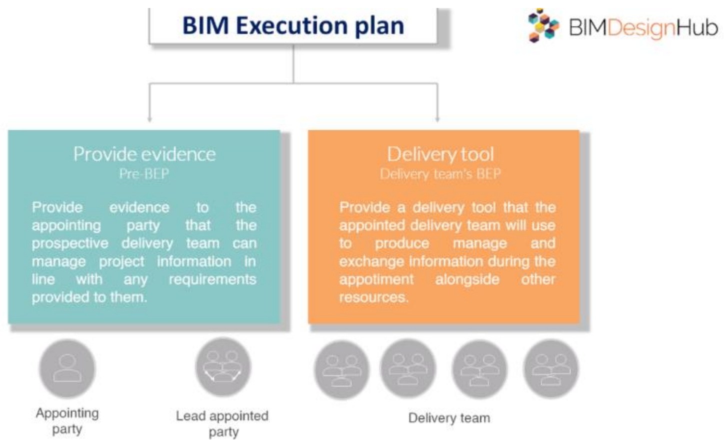

Figure 8 – BIM Execution Plan types (BIMdesignhub, 2021)

A well-completed BEP should address the following of information (Penn State, 2019):

1. BEP Overview: The motivation and reason for creating the document.

2. Project Information: The specification of the project information such as project number, code, location, description, size and critical schedule dates for future reference.

3. Key Project Contacts: Must include the contact information for key project leaders and stakeholders involved in the process. In addition, the Master Information Delivery Plan, with the project phases and deadlines.

4. Project Goals / BIM Objectives: This section must list the strategic value and specific uses for BIM on the project as defined by the project team.

5. Organizational Roles and Responsibilities: The nomination of the BIM roles to execute the assigned tasks throughout the stages of the project.

6. BIM Information Exchanges: The model elements and level of detail to guarantee interoperability and information exchanges.

7. BIM Process Design: Illustrate the execution process through the use of process maps.

8. BIM and Facility Data Requirements: The client's requirements for BIM.

9. Collaboration Procedures: The team's electronic and collaboration activity procedures, such as file structures, file permissions and typical meeting schedules.

10. Model Quality Control Procedures: A procedure to verify if the project participants meet the defined requirements.

11. Technology Infrastructure Needs: The hardware, software and network infrastructure required to execute the project.

12. Model Structure: Define the items such as model structure, file naming structure, coordinate system, and modelling standards that must be followed.

13. Project Deliverables: The documents that the team must deliver to the client.

14. Delivery Strategy / Contracts: The specification of the contract mobility, such as design-build or design-bid-build etc. This scope will impact the language that should be incorporated into the project to ensure BIM implementation.

2.5.5. Level of Information Need and Information Delivery Specification

The Level of Information Need is defined as the framework for specifying the information required about a BIM project at a given point. It provides a structured way to state the information needed, and for what purpose, ensuring requirements are clear and proportional (ISO 19650-1, 2018).

Within the UK BIM Framework, the Level of Information Need is applied as a scalable and flexible requirement definition tool, supporting the creation of Exchange Information Requirements (EIR) and subsequent information deliverables across a project. It ensures that information requests remain proportionate to project goals and asset management needs, reducing ambiguity between clients and delivery teams. The Levels of Information Need definition guarantees that the needed information will be produced for the right actor and delivered at the right time to the specified receiver (Figure 9). It is broken into three components that can be used independently or together at different project stages, whether at an organisational, asset, or project level (UK BIM Framework – Guidance Part D, 2021).

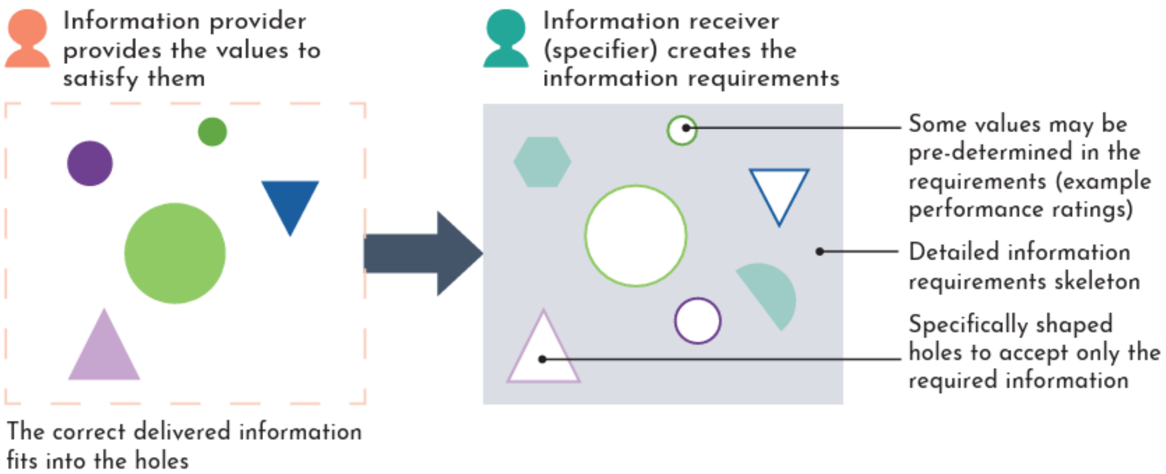

Figure 9 – Level of Information Need as the Information requirements skeleton. Source: UK BIM Framework (UK BIM Framework, 2021)

In turn, the Information Delivery Specification (IDS) is a standard defined under buildingSMART International as part of the openBIM framework. The IDS provides a machine-readable way to validate the information requirements exchanging within BIM. Unlike documented information requirements, such as EIR or Level of Information Need, the IDS is a formal schema-based definition that specifies which information objects, properties, and values are required, making it possible to automatically check models against requirements. IDS therefore address the gap between human-readable requirements and digital validation processes (buildingSMART, 2024).

In practice, IDS can be applied throughout the project delivery process (Figure 10), from design through construction and into asset management. It is typically derived from higher-level requirements, such as those outlined in an EIR or defined through Level of Information Need and translated into digital validation rules. These rules can be run against IFC (Industry Foundation Classes) models to ensure compliance with agreed standards, such as naming conventions, property sets, classification codes, or levels of information need. This makes IDS a powerful tool for ensuring data quality and consistency in information exchanges across different platforms and stakeholders (buildingSMART, 2024).

As complementary tools for the model verification through IDS files, it is important to define two elements that make part of the IDS workflow, which are BCF and bSDD. A BCF file is a BIM Collaboration Format file, defined as an open, vendor-neutral standard to communicate issues, and viewpoints related to BIM models among the project team, but mainly used by the delivery team. The BSDD is the buildingSMART Data Dictionary, which enables consistent interpretation of terms and attributes across different software platforms and languages (buildingSMART, 2024).

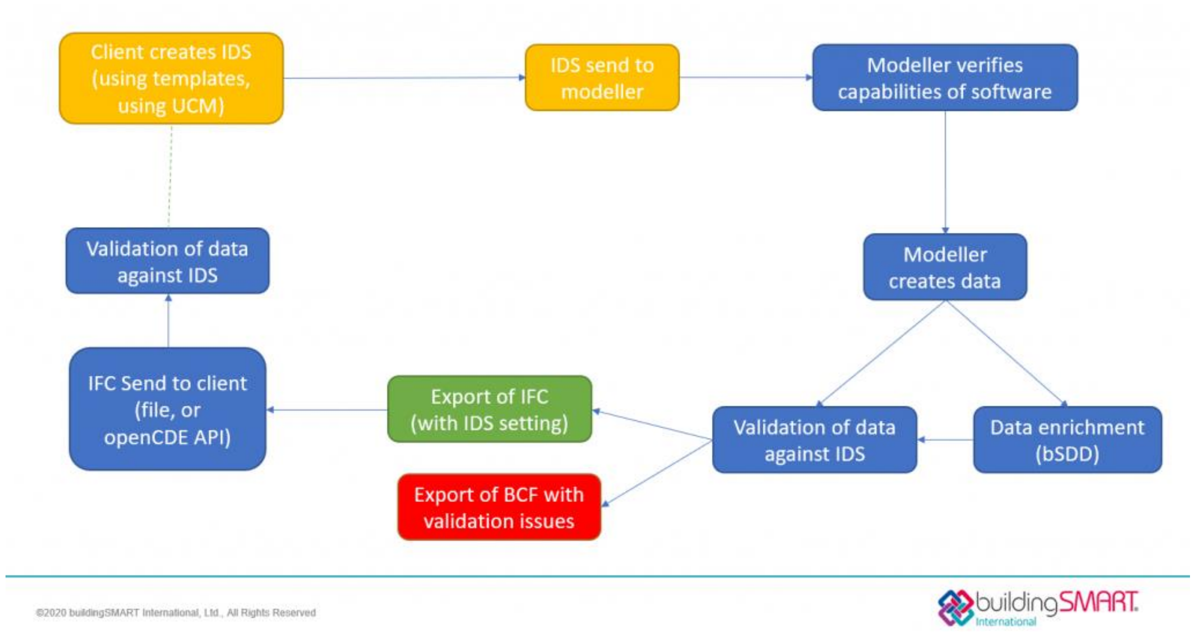

Figure 10 – IDS workflow (buildingSMART, 2024)

By combining Level of Information Need specification tables and IDS validation, clients and project teams benefit from greater reliability in BIM deliverables, reduced errors and manual data checking. Within the UK BIM Framework and ISO 19650 context, IDS is seen as a complementary mechanism: EIRs define what information is needed, Level of Information Need clarifies the level of detail, and IDS provides the technical digital specification that ensures these requirements can be validated (buildingSMART, 2024).

2.5.6. Classification Systems and Quantity Take-Off (QTO)

Classification systems in the context of BIM are structured frameworks used to organize and categorize building elements, spaces, and activities in a standardized way. Examples include UniClass, OmniClass, and MasterFormat, each developed to support interoperability, cost estimation, data exchange, and effective communication among stakeholders. In prefabrication projects, where coordination across complex supply chains is critical, classification systems play a central role in ensuring that design intent, material specifications, and production requirements are interpreted consistently by all parties involved. Standardized classification thus enhances collaboration and reduces the risk of misinterpretation or data loss when information is transferred across platforms and disciplines (Sacks et al., 2018).

In Brazil, the ABNT NBR 15965 standard provides a national framework for the classification of construction information. Adapted to the Brazilian construction context, ABNT NBR 15965 establishes a hierarchical structure for organizing elements, components, spaces, activities, and construction processes. This classification is especially relevant for BIM-enabled workflows because it enables consistent integration of data into QTO processes, cost estimation systems, and facility management databases. By aligning with international practices while reflecting local needs, ABNT NBR 15965 supports both national standardization and international interoperability, ensuring that

Brazilian projects can benefit from structured, efficient, and transparent information management (ABNT, 2015).

The ABNT NBR 15965 system organizes construction information into levels and groups, starting from broad categories, such as construction entities, and becoming more detailed, such as elements, components, and products. Each item is assigned a classification code that identifies its place in the hierarchy. The normative is divided into multiple parts, each focusing on a different group of construction information: Part 1, Terminology and Structure, defines the framework and classification principles; Part 2, Characteristics of Construction Objects, focuses on properties and attributes; Part 3, Construction Processes, describes activities and processes; Part 4, Construction Resources, establishes the structure for the classification systems 2C products, 2N Functions and 2Q Equipment; Part 5, Construction Results, establishes the structure for the classification systems 3E Elements, and 3RWork Results. Part 6, Construction Units and Spaces, establishes the structure for the classification systems 4U Units and 4A Spaces; and finally, Part 7, Project Information, applies the classification to design documentation.

When classification systems are embedded within BIM models, they provide the structural framework that links objects to cost databases, procurement schedules, and production workflows, improving traceability and accountability throughout the project lifecycle. The Quantity Take-Off (QTO) processes benefit greatly from BIM integration and classification systems, as digital models enable the automated and accurate extraction of quantities directly from the model based on the element classification. This capability improves efficiency, reduces human error, and supports real-time updates as design changes occur. For prefabrication projects, QTO is particularly important in managing material efficiency, optimizing production planning, and maintaining cost control. (Sacks et al., 2018).

3. CASE STUDY

Following the establishment of a comprehensive literature review that consolidates the principal knowledge within the field, this chapter introduces the case study company, which provides the foundation for the development and application of the proposed framework. The study focuses on a real-world organization operating in the prefabricated building construction sector in Brazil. The primary objective is to examine the processes undertaken within the company's Project Department, with particular attention to understanding how and why these processes occur. This analysis subsequently serves to determine which BIM methodologies are most applicable for enhancing project management practices within the company's specific organizational context.

The investigation involved a thorough understanding of the company's profile and organizational structure, mapping the main processes of the Project Department, assessing the company's current BIM maturity level, and evaluating its potential for implementing ISO 19650 guidelines to improve workflows and best practices.

3.1. Company Profile

Founded in 2013, KRONAN operates in the Brazilian civil construction market using an industrialized system of prefabricated concrete panels. Inspired by Finnish construction methodologies, the company integrates efficiency, quality, and modern architectural design into its solutions.

KRONAN employs the BIM methodology throughout its operations and owns a dedicated manufacturing facility in Itupeva, São Paulo. Through its Off-Site Construction model, the company delivers projects up to three times faster than conventional construction methods while maintaining high precision standards.

3.1.1. Organizational Structure

KRONAN is composed of a multidisciplinary team structured to meet the demands of construction projects with a high level of technical expertise. The company's general organizational chart (Figure 11) illustrates its matrix structure, which integrates diverse disciplines and roles across projects. This structure offers both flexibility and a high degree of collaboration between different areas of knowledge.

The company is led by a Board of Directors, responsible for developing KRONAN's strategic vision and innovative business model. Reporting to the board is the General Director, who oversees the company's technical operations and ensures alignment with its strategic goals. Supporting functions include the following departments:

- Administrative Department: Manages internal operations, ensuring organizational efficiency and regulatory compliance.

- Commercial Department: Serves as the initial interface with clients, responsible for business development and project acquisition.
- Planning Department: Prepares project schedules and budget estimates aligned with the client's requirements and overall project scope.
- Project Department: Develops architectural and structural designs, including detailed drawings for precast concrete panels.
- Precast Manufacturing Department: Executes the fabrication of concrete panels with industrial precision and quality control.
- Construction Department: Handles the logistics, transportation, installation, and on-site execution of construction activities.

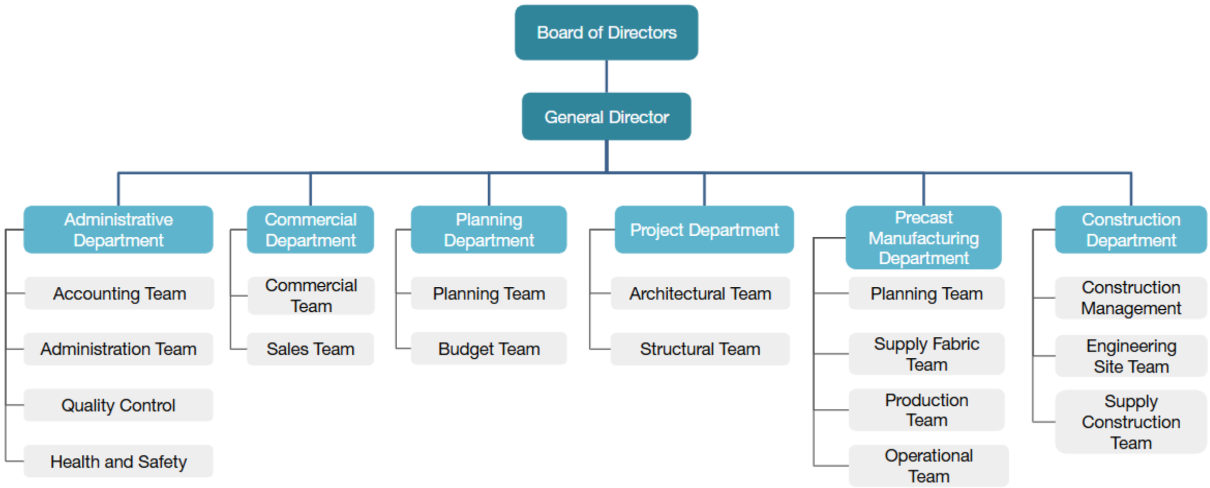

Figure 11 – Company's general organizational chart

This is a complex organizational structure that requires strong collaboration between departments. The Administrative Department serves as the foundation for the entire company's operations. The Commercial Department plays an important role in acquiring new projects and maintaining client relationships.

To ensure project viability within the company, the Commercial Department must work closely with the Planning Department, which, in turn, relies on the Project Department to provide the necessary design solutions for contract development. Next, the Manufacturing Department follows the project guidelines defined by the Project Department and adheres to the schedule established by the Planning Department.

Finally, the Construction Department represents the outcome of effective coordination among all previous departments, ensuring the successful execution of the project on site.

3.1.2. Organizational Mission, Vision, and Values

KRONAN aims to transform the Brazilian construction sector by delivering excellence in quality, efficiency, and technological innovation. Its work is driven by continuous improvement, applied research, and a strong commitment to clients and partners.

By 2030, KRONAN envisions itself as a nationally recognized benchmark in industrialized construction and precast concrete. It seeks to lead the modernization of the sector through cutting-edge technologies, optimized processes, and the delivery of high-performance projects.

KRONAN's operations are guided by the core values of responsible innovation, professional commitment, people development, ethical conduct, transparency, and pursuit of quality.

3.2. Current Practices and Process

Currently, the establishment of a commercial relationship between the client and the case study company may occur through two distinct pathways. The first, referred to as the Design-Construction Scope, occurs when the client approaches the company seeking both the development of an architectural design and the subsequent delivery of the building using prefabricated panels manufactured by the company. The second, referred to as the Redesign-Construction Scope, arises when the client already possesses an architectural design and engages the company to adapt the existing design to Kronan’s construction system for effective delivery.

The initial definition of the project scope activates the company’s Project Department, giving rise to distinct workflows depending on the pathway followed. For the purposes of the present study, the Redesign-Construction Scope was selected as the focus of analysis, as it more accurately reflects the company’s current commercial practices. Consequently, the processes that initiate the Design-Construction Scope will not be addressed in the subsequent sections; the discussion will focus exclusively on the Redesign-Construction Scope.

In practice, the primary stakeholders involved in the Redesign-Construction Scope are:

- **Client:** The party with the construction demand, initiating the project and procuring services.
- **Architectural Office:** responsible to design the architectural language project. Has its authoring.
- **Kronan’s Project Department:** Responsible for adapting the original architectural design to Kronan’s prefabricated construction system. This department is subdivided into two disciplines:
    - **Architectural Team:** Tasked with redesigning the original project while preserving its architectural language.

- **Structural Team:** Ensures the structural performance and efficiency of the redesigned solution.

- **MEP Subcontractor:** A specialized company responsible for developing the mechanical, electrical, and plumbing (MEP) installations within the project.

3.2.1. Project Acquisition - AS IS Process Map

Following the examination of contractual relationships and stakeholder roles from a general perspective, this study now turns to the current processes within the Project Department, which is established as the central unit of analysis in the present case study. This subsection introduces the first key process undertaken by the department within the Redesign–Construction Scope: the Project Acquisition Process. Within the Project Acquisition Process, the Project Department is responsible for developing a BIM model that incorporates a preliminary prefabricated redesign solution, aimed at adapting an architectural project that was not originally conceived for prefabrication. At this stage, no formal contract has yet been signed. Accordingly, the BIM model serves two primary purposes: (i) to support the preparation of a commercial proposal through accurate quantity take-offs, and (ii) to establish the initial engagement between a potential client and the company, thereby fostering the basis for a prospective contractual relationship.

To better illustrate the interdepartmental communication involved in the Project Acquisition Process, it has been divided into two process maps. The first, titled “AS IS Project Acquisition Process Map” (Figure 12), provides an introduction and summary of the overall workflow. The second process map, titled “AS IS Modelling for Budgeting Subprocess” (Figure 13), represents a subprocess derived from the Project Acquisition Process. It details the internal workflow within the Project Department to develop the preliminary BIM model for cost estimation and project feasibility assessment. A comprehensive mapping of the Modelling for Budgeting subprocess, it is also provided in APPENDIX 1.

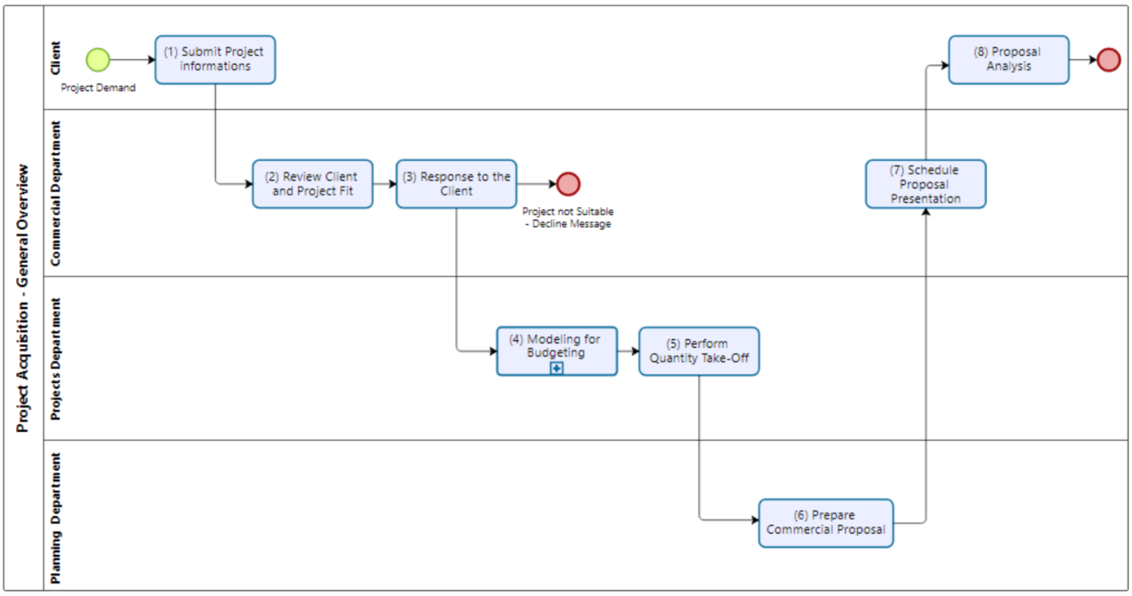

Figure 12 – AS IS Project Acquisition Process Map

The Project Acquisition Process Flow consists of (Figure 12):

(1) **Submit Project Information:** The client initiate contact submitting the architectural project.

(2) **Review Client and Project Fit:** The Commercial Department reviews the project and client profiles to ensure they meet the company's minimum eligibility criteria, such as minimum construction area required for viability, location of the site within the company's operational area, initial budget alignment, and availability of acceptable payment methods.

(3) **Response to the Client:** If the project does not meet the company's basic requirements, the Commercial Department sends a formal decline message to the potential client, clearly stating which criteria were not met, and why the Kronan construction system cannot be applied and the process ends. If the client and project meet the minimum eligibility criteria, the Project Department is activated.

(4) **Modelling for Budgeting:** The Project Department proceeds to develop a prefabricated design solution that remains consistent with the original architectural language (this task creates a subprocess detailed in the Figure 13, 14 and 15).

(5) **Perform Quantity Take-Off:** the Project Department performs a quantity take-off.

(6) **Prepare Commercial Proposal:** Based on the quantity take-off provided by the project department, the Planning Department conducts a cost estimation and finalizes the commercial proposal.

(7) **Schedule Proposal Presentation:** The Commercial Department schedules proposal presentation to the client.

(8) **Proposal Analysis:** The client reviews the commercial proposal and provides a final decision regarding the contract to the Commercial Department.

As explained previously, the "(4) Modelling for Budgeting" task generates a subprocess, which is presented in general terms in Figure 13 to provide a high-level overview. Figure 14 and 15 provide a more detailed representation of this subprocess. The purpose of presenting the information across these three figures is to allow for an appropriate and readable scale, ensuring clarity at both the overview and detailed levels.

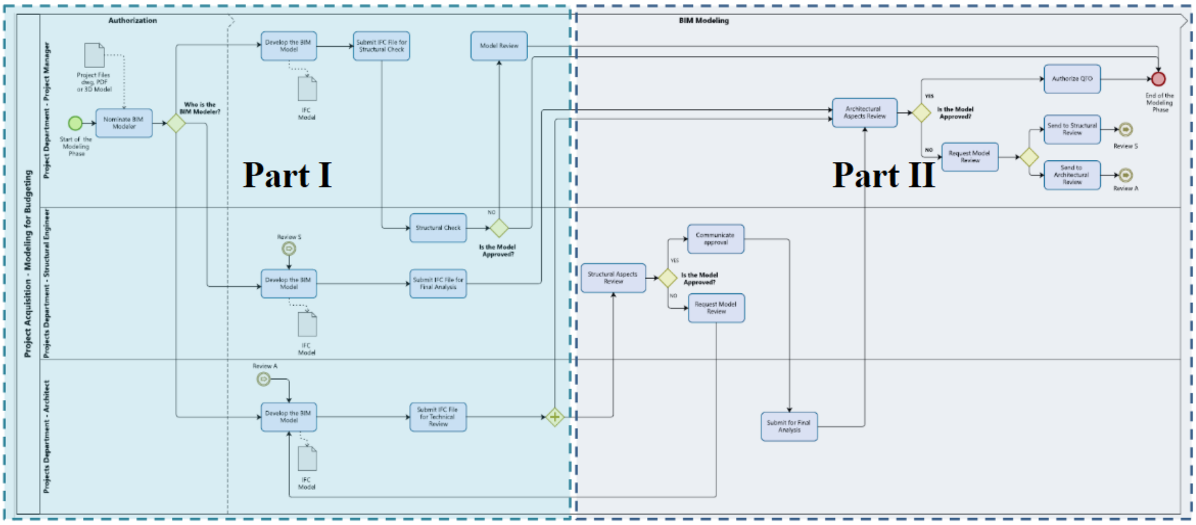

Figure 13 – AS IS Modelling for Budgeting Subprocess – General Overview

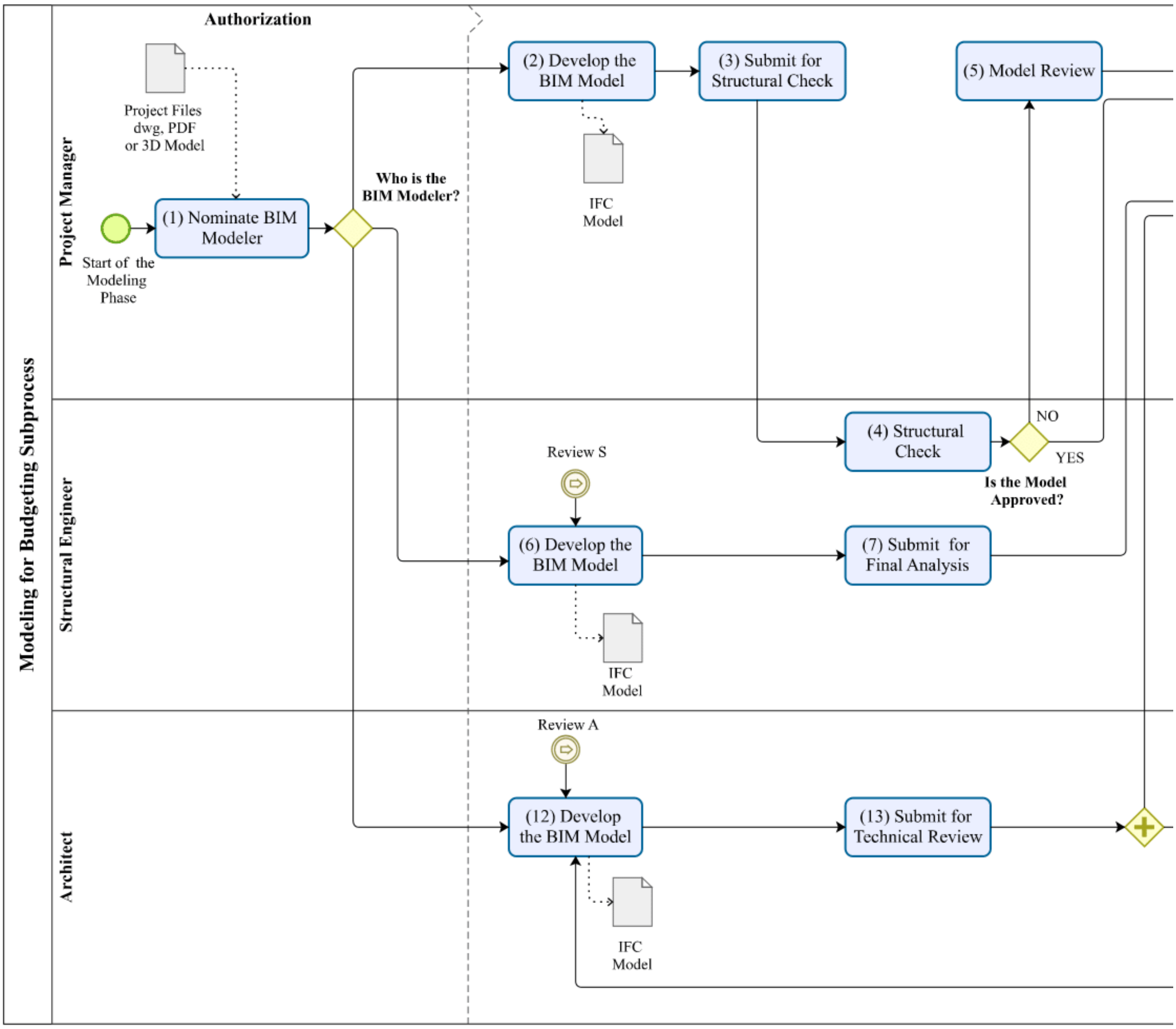

Figure 14 – AS IS Modelling for Budgeting Subprocess - Part I

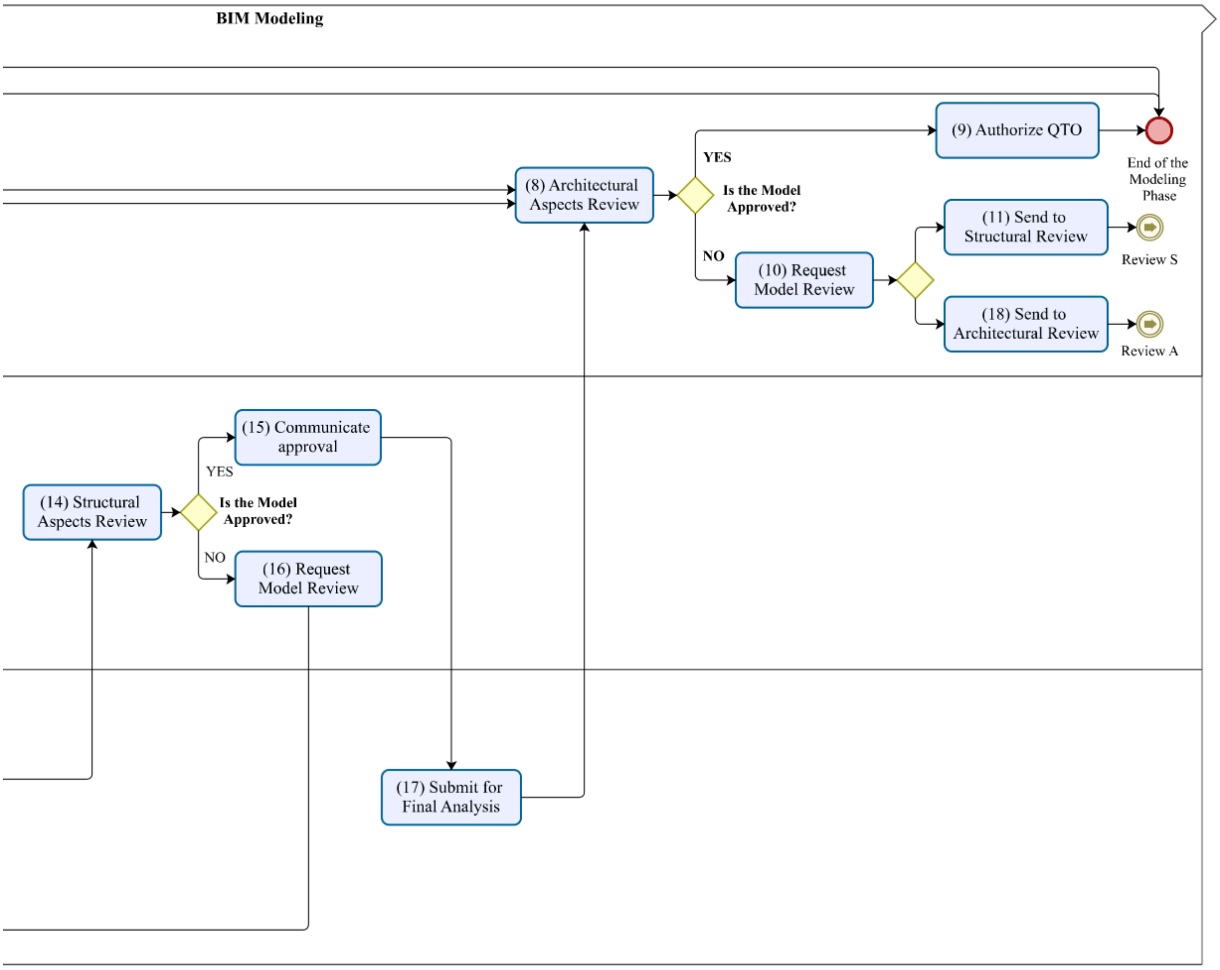

Figure 15 –AS IS Process Map of the Project Department for Project Acquisition - Part II

The AS IS Modelling for Budgeting Subprocess Flow consists of (Figure 14 and 15):

(1) Nominate BIM Modeler: The Project Manager nominates the responsible party for the modelling task based on team availability and the project's complexity. If the project is classified as highly complex (e.g. few supporting walls, large spans, mixed structures or unusual geometry), the modelling is carried out by either the Project Manager or the Structural Engineer. For medium or low-complexity projects, the task is assigned to one of the team’s architects. This decision-making step creates a gateway, which will impact the following stages of the modelling process.

(2) Develop the BIM Mode – Project Manager: In the first decision-making option, the Project Manager is responsible for developing the BIM model.

(3) Submit IFC File for Structural Check: After modelling, the Project Manager exports the project file in IFC format for structural verification.

(4) Structural Check: The structural engineer analyses the model according to structural principles.

(5) Model Review: If the model is not approved, the Project Manager must revise it based on the structural engineer's feedback. However, if the model fully complies with structural principles, the Project Manager finalizes the Modelling for Budgeting subprocess and performs the quantity take-off.

(6) Develop the BIM Model – Structural Engineering: In the second decision-making option of the gateway "Who is the BIM Modeler?", the team member responsible for the modelling phase is the structural engineer.

(7) Submit IFC File for Final Analysis: After developing the model, the structural engineer submits the IFC file for architectural aspects review by the Project Manager.

(8) Architectural Aspects Review: The structural engineer analyses the model according to architectural principles.

(9) Authorize QTO: If the model is approved, the structural engineer can finalize the modelling phase and perform quantity take-off.

(10) Request Model Review: If the model is not aligned with the architectural language of the original project, the Project Manager request model review.

(11) Send to Structural Review: The Project Manager communicates the structural engineer the request for model review. The structural engineer must review the model and submit it to (8) Architectural Aspects Review again until the model be approved and authorized to quantity take-off.

(12) Develop the BIM Model - Architect: In the third decision-making option of the gateway "Who is the BIM Modeler?", the team member responsible for the modelling phase is the architect.

(13) Submit IFC File for Technical Review: After the model development, the architect submits simultaneously the model for architectural and structural reviews.

(14) Structural Aspects Review: The structural engineer analyses the model according to structural principles, while the Project Manager perform the (8) Architectural Aspects Review. Only after the consent of these two disciplines the architect is authorized to perform the quantity take-off.

(15) Communicate approval: if the model fully complies with structural principles, the structural engineer communicates the architect the approval.

(16) Request Model Review: if the model not fully complies with structural principles, the structural engineer request model review to the architect.

(17) Submit for Final Analysis: after reviewing the model by structural and architectural aspects, the architect submit the model again to the Project Manager Final analysis.

(18) **Send to Architectural Review:** if the model is not approved by the Project Manager, the architect reviews the model until achieve the final approval to run quantity take-off.

An important detail of this process is that the team member who developed the BIM Model is also responsible for the next task of performing quantity take-off. Without exception, the professional responsible for the BIM model will also be responsible for the quantity extraction, as these two activities are inherently linked and must be carried out by the same individual.

After mapping the Project Acquisition Process, it becomes evident that the workflow encourages dynamic interaction among the Project Manager, Structural Engineer, and Architects. However, this collaborative environment can occasionally lead to miscommunication between departments and professionals involved in the process.

The first issue identified is a lack of structured information transfer between the Commercial Department and the Project Department. Once the Commercial team verifies that the client and project meet the minimum eligibility criteria, the Project team does not receive any formal documentation outlining the client's profile, expectations, and specific requirements. This absence of key information can negatively affect the development of the prefabricated design solution, potentially leading to misaligned outcomes.

The second issue concerns the misalignment between deadlines established by the Planning Department and the internal schedule of the Project Department. This discrepancy can lead to unrealistic expectations for the client regarding the delivery timeline of the commercial proposal. Furthermore, there is a noticeable lack of clarity regarding roles and responsibilities during the modelling phase, particularly in terms of who is responsible for generating the model and what specific information should be included. For example, a recurring challenge faced by the Planning Department is the lack of critical design details, such as the adopted panel thickness, the orientation of panel assembly (vertical or horizontal), the precise placement and thickness of hollow-core slabs, and whether a complementary roof system is included in the solution.

The absence of information at the appropriate stage leads to inefficiencies in cost estimation and project planning. Overall, the lack of standardized steps and clearly defined responsibilities contributes to inconsistencies in workflow, delays, and variations in the quality of deliverables. These communication gaps, scheduling conflicts, and role ambiguities have been identified as critical pain points with strong potential for process improvement, especially in terms of standardization and efficiency.

3.2.2. Executive Project - AS IS Process Map

The Executive Project Process begins once the Project Acquisition Process concludes with the client's acceptance of the commercial proposal. This process was mapped using the same methodology applied to the previous process maps. An overview of the workflow was first developed (Figure 16), followed by a detailed representation of the Executive Project Development subprocess (Figure 17) and its subdivisions. The use of multiple figures ensures that the process is presented at an appropriate and readable scale, while maintaining both clarity and analytical depth. A comprehensive mapping of the Executive Project Development Subprocess, it is also provided in APPENDIX 2.

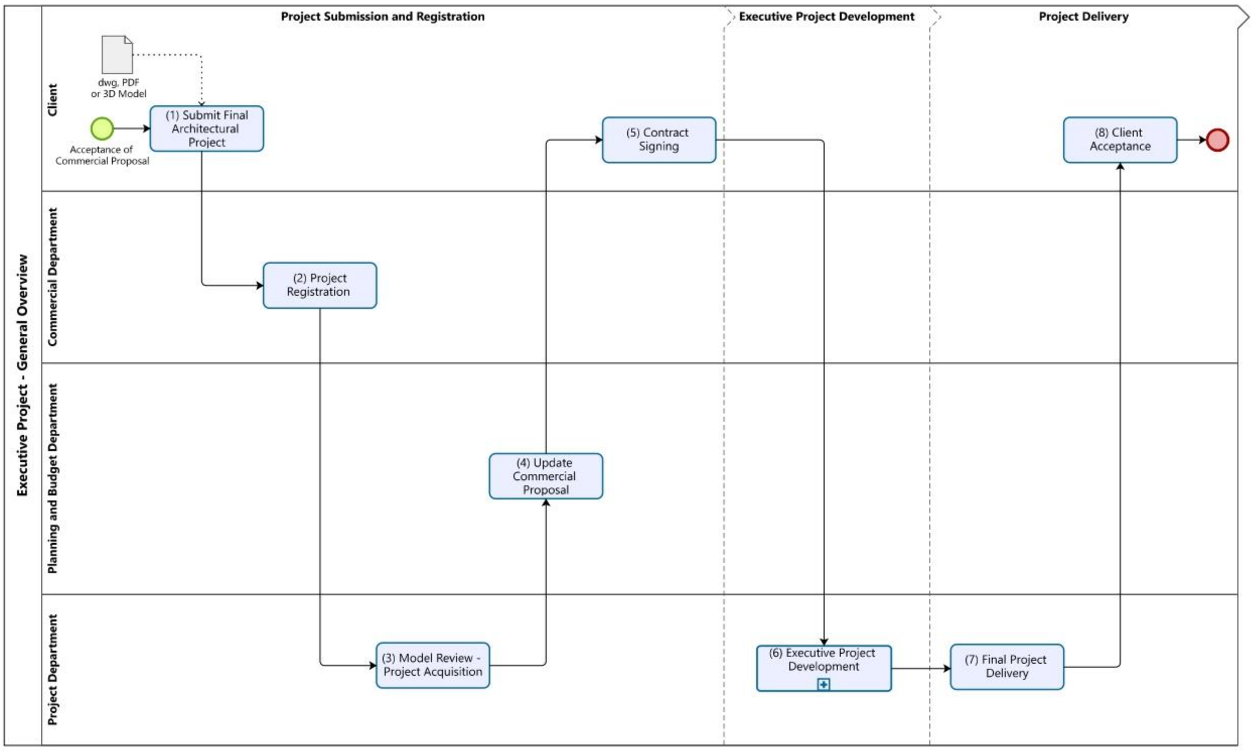

Figure 16 – AS IS Executive Project Process Map

The AS IS Process Map for Executive Project - General Overview Flow consists of (Figure 16):

(1) **Submit Final:** The client submits the final architectural project developed by the external Architectural Office.

(2) **Project Registration:** The Commercial Department registers the client and project information, which triggers the involvement of the Project Department.

(3) **Model Review - Project Acquisition:** The Project Department reviews the architectural redesign and updates the Project Acquisition Model accordingly.

(4) **Update Commercial Proposal:** The commercial proposal is updated according to the model review.

(5) **Contract Signing:** The Commercial Department providences the contract signature with the client.

(6) **Executive Project Development:** The contract signature marks the official start of the Executive Project Development subprocess.

(7) **Final Project Delivery:** This stage consists of the compilation and formal handover of all project documentation to the client.

(8) **Client Acceptance:** The client reviews the delivered documentation and, upon approval, formally concludes the Executive Project Process.

After the general overview of the process, the focus shifts to the detailed activities within the Project Department to perform the Executive Project Development subprocess (Figure 17), and its respective detailed parts (Figure 18, 19 and 20).

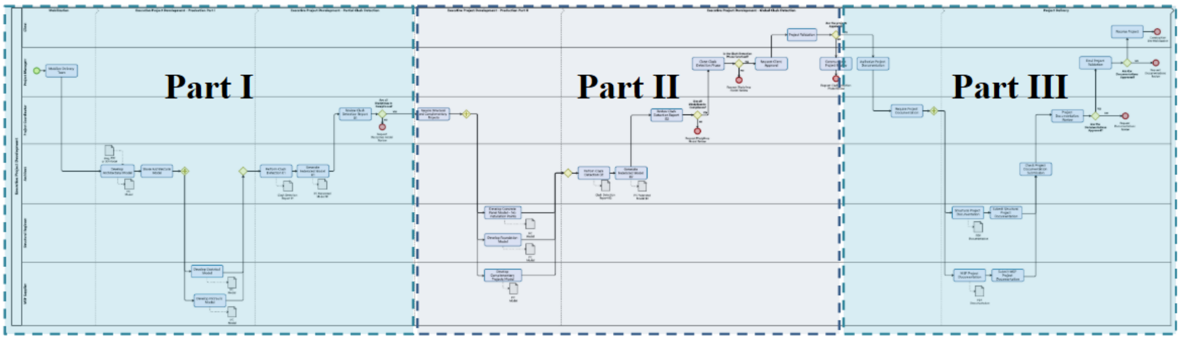

Figure 17 – AS IS Executive Project Development Subprocess – General Overview

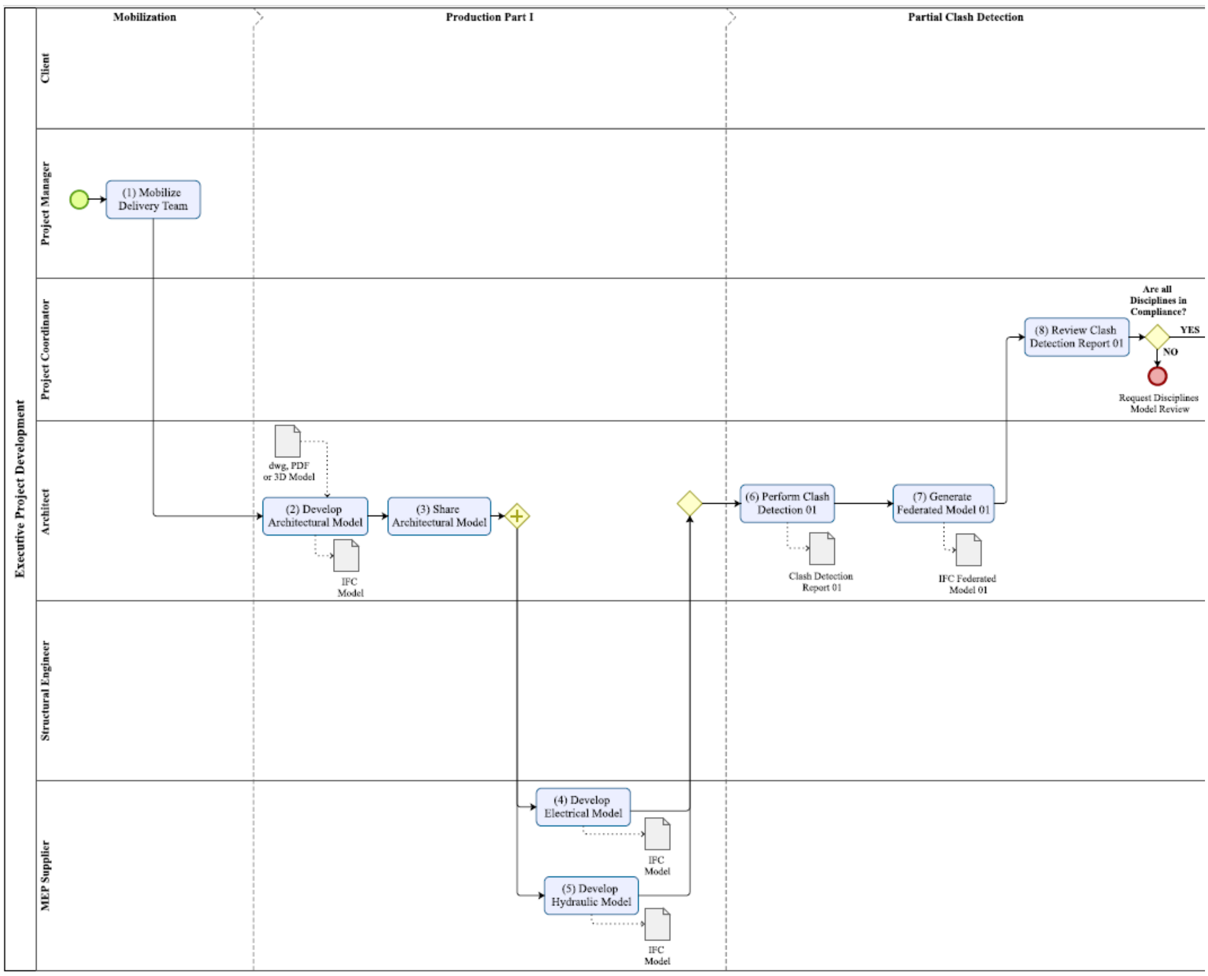

Figure 18 – AS IS Executive Project Development Subprocess Map - Part I

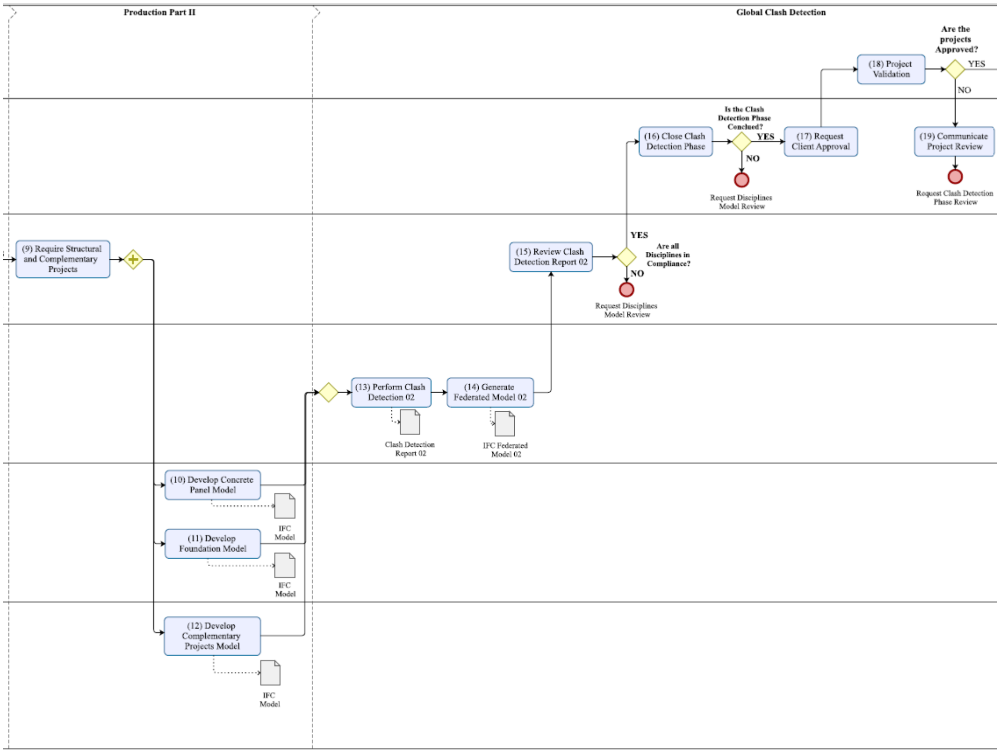

Figure 19 – AS IS Executive Project Development Subprocess Map - Part II

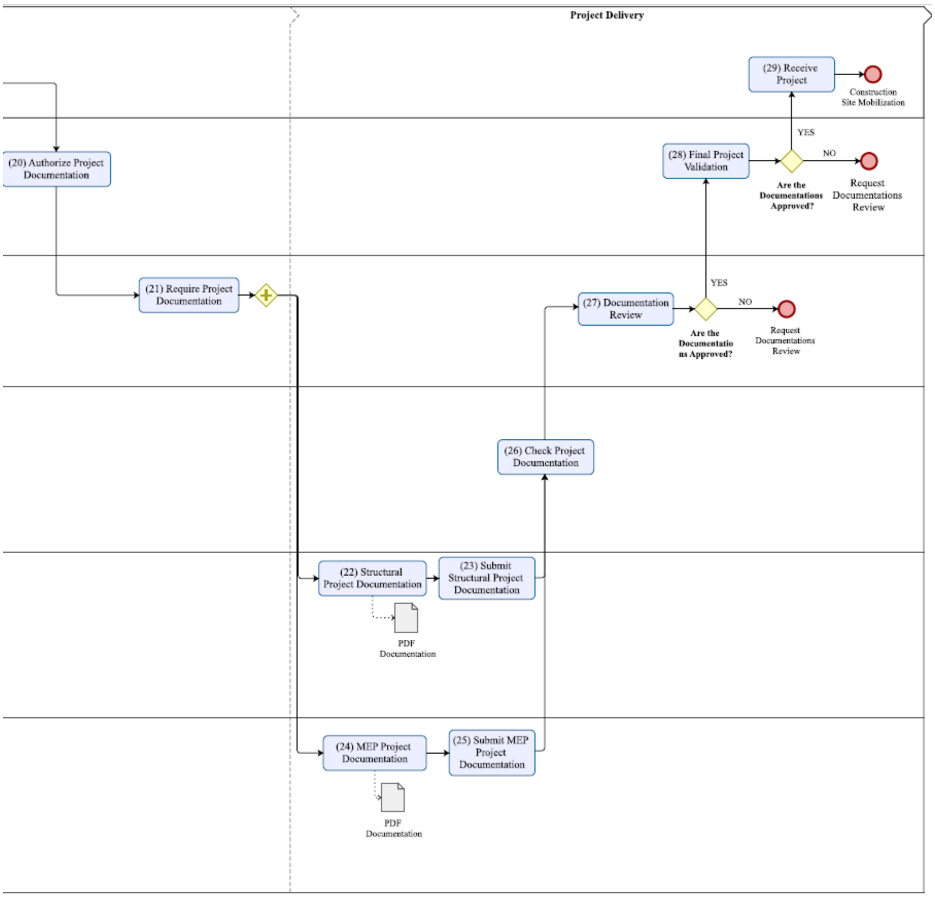

Figure 20 – AS IS Executive Project Development Subprocess Map - Part III

The AS IS Subprocess Executive Project Development Flow consists of (Figure 18, 19 and 20):

(1) **Mobilize Delivery Team:** The Project Manager assembles the project delivery team by selecting the professionals who will be dedicated to the project.

(2) **Develop Architectural Model:** Once the architect is assigned, they are responsible for developing the complete architectural model based on the client's submitted design. At this stage, it is essential that the model includes information about the terrain and site location, internal and external walls (including concrete panels predicted in Acquisition Project Model), openings, roofs, floors, installation points, and any other relevant details necessary for full project compatibility.

(3) **Share Architectural Model:** Once the architectural model is complete, it is shared with the MEP team, which develops the initial MEP system designs.

(4) **Develop Electrical Model:** the electrical discipline model is design by the MEP team member.

(5) **Develop Hydraulic Model:** the hydraulic discipline model is design by the MEP team member.

(6) **Perform Clash Detection 01**: The discipline models return to the architect for the first clash detection analysis.

(7) **Generate Federated Model 01:** The architect generates the First Federated Model.

(8) **Review Clash Detection Report 01:** The clash detection is checked by the Project Coordinator. In case the MEP design is not approved, the Project Coordinator requests the model review.

(9) **Require Structural and Complementary Projects:** After the MEP design approval by the Project Coordinator, the project is forwarded to the Structural Engineering team to develop the panel and foundation models.

(10) **Develop Concrete Panel Model:** The structural concrete panel project is developed by the structural engineer. During this phase, the structural engineer verifies and adjusts the preliminary panel dimensions as needed.

(11) **Develop Foundation Model:** The foundation project is developed by the structural engineer.

(12) **Develop Complementary Projects Model:** The complementary projects are developed by the subcontractors, such as photovoltaic and pool system suppliers, if applicable.

(13) **Perform Clash Detection 02:** The architect performs a second clash detection.

(14) **Generate Federated Model 02:** The architect generates a second Federated Model.

(15) Review Clash Detection Report 02: The Project Coordinator conducts a thorough review. If the project is approved, the project is forwarded to the Project Manager. If the project is nor approved, it is forwarded to the task team again to models review (architectural, structural and MEP).

(16) Close Clash Detection Phase: The Project Manager performs a final check before submitting the project to the client for feedback and validation.

(17) Request Client Approval: the project is submitted for the client validation.

(18) Project Validation: The client analyses the project and send feedback about the project solutions.

(19) Communicate Project Review: If the project is not approved by the client, it is requested a project review.

(20) Authorize Project Documentation: After the client approval, the Project Manager authorizes the start of the documentation phase.

(21) Require Project Documentation: The Project Coordinator communicates the start of the documentation phase to the task team.

(22) Structural Project Documentation: The structural engineer produces the final discipline documentations.

(23) Submit Structural Project Documentation: The structural engineer submits the final discipline documentations for validation.

(24) MEP Project Documentation: The MEP specialist produces the final discipline documentations.

(25) Submit MEP Project Documentation: The MEP specialist submits the final discipline documentations for validation.

(26) Check Project Documentation Submission: The architect checks the documentations sent by the structural and MEP disciplines.

(27) Project Documentation Review: The project Coordinator reviews the documentations sent by the structural and MEP disciplines.

(28) Final Project Validation: The project is submitted for the Project Manager Validation.

(29) Receive Project: The project is delivered to the client final approval.

The analysis conducted following the process mapping revealed persistent issues related to communication breakdowns, information gaps, and rework, all of which could be mitigated through the implementation of standardized protocols for information exchange. A primary issue identified is the inconsistent quality and completeness of the project documentation submitted by the client. As the architectural design is typically developed by an external lead-appointed party, the level of detail provided to Kronan's Project Team is often unpredictable. There is no guarantee as to whether the documentation will include floor plans, elevations, sections, or 3D models, nor is there consistency in the file formats received (e.g., DWG, PDF, IFC). This uncertainty compromises the efficiency and accuracy of the initial design phase.

Another significant challenge occurs post-contract signing, where miscommunication between the Commercial, Planning, and Project Departments may lead to inconsistencies between the BIM model, the contractual scope, and the client's expectations. Such discrepancies can result in contract amendments, erosion of client trust, and unexpected costs for the company.

Within the design development and clash detection phases, it was observed that client approval is typically deferred until the final stages of the process. Introducing intermediate approval checkpoints, particularly during clash detection, could reduce the volume of rework required and enhance design quality. Nevertheless, one of the most complex challenges to manage remains the frequent submission of change requests and the lack of clearly defined project parameters, which hinder the efficiency of the design phase and reduce overall process controllability.

3.3. Company BIM Maturity Assessment

To assess the current BIM maturity of Kronan's project team, the BIM Maturity Matrix (BIM^3) developed by the BIM Excellence Initiative (BIMe) was applied. This structured knowledge tool evaluates an organization's BIM capability across four key dimensions:

- Technology: Assesses the use of software applications, hardware infrastructure, and network solutions supporting the production, management, and delivery of project data and digital deliverables.
- Process: Evaluates workflows, resources, activities, and outputs, as well as leadership practices that influence the consistency and efficiency of BIM adoption.
- Policy: Examines preparatory, regulatory, and contractual mechanisms that support and govern BIM implementation, including internal guidelines, mandates, and protocols.
- Organizational: Analyses BIM adoption and diffusion at macro (industry), meso (organizational), and micro (project) scales, and tracks progression through three maturity stages: Object-Based Modelling, Model-Based Collaboration, and Network-Based Integration.

Following the evaluation, a graphic representation was created to illustrate Kronan's BIM maturity level across the four dimensions (Figure 21). Detailed results are presented in APPENDIX 3.

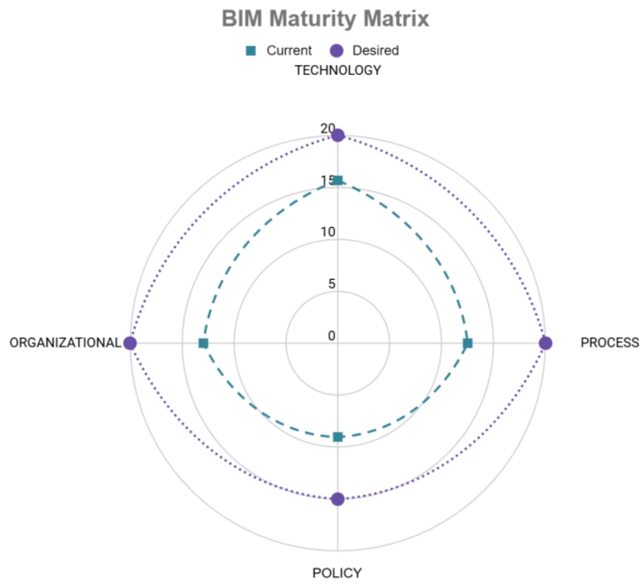

Figure 21 – Company's BIM Maturity Matrix, Current and Desired Levels

3.3.1. Analysis of BIM Maturity Results

The assessment of Kronan's BIM maturity using the BIM Maturity Matrix (BIM^3) provided valuable insights into the organization's current capabilities and areas for improvement:

- Technology: The results indicate that Kronan has a solid technological foundation, including software and hardware infrastructure. Minimal templates have been implemented, and BIM platforms are used for both 2D and 3D deliverables. While interoperable data exchange exists, it is not yet well defined. The equipment is adequate to support BIM workflows, and a centralized platform is in use for collaboration, sharing, and data storage, despite not having well-defined usage patterns.

- Process: The organizational environment promotes productivity through appropriate tools and workspace configurations. BIM roles and responsibilities are defined among stakeholders. Furthermore, internal documents outline good modelling practices, and senior leadership demonstrates a unified vision of BIM as both a process and a driver of technological transformation. Despite possessing a supportive infrastructure and organizational commitment toward technological implementation, the company faces significant challenges in establishing and executing well-defined processes.

- Policy: Kronan offers training upon request and maintains basic BIM guidelines; however, the alignment between training initiatives and organizational strategies remains unclear to the task teams. Furthermore, the absence of a defined training schedule hinders the ability to systematically assess the impact of such training on team productivity. The existing BIM guidelines require further development, particularly in areas related to modelling standards and quality assurance plans, in order to support consistent and high-quality project deliverables. From a contractual standpoint, mechanisms for information sharing must be improved to ensure the confidentiality of sensitive data, and a formal system for BIM-related conflict resolution should be established. Overall, the presence of clearly defined BIM requirements, roles, and responsibilities within contractual documents is insufficient. Moreover, stakeholder understanding of BIM policy obligations is limited, which affects their ability to accurately fulfil and document task responsibilities. This lack of clarity underscores the need for more robust policy dissemination and training to ensure alignment and accountability across all project participants.

- Organizational: Kronan demonstrates moderate progress in organizational BIM adoption. At the micro level, BIM practices are present within project teams. At the meso level, however, BIM integration across departments remains fragmented. At the macro level, the company aims to establish more comprehensive strategies that align BIM goals with broader business objectives. Additionally, progression through the BIM maturity stages, Object-Based Modelling, Model-Based Collaboration, and Network-Based Integration, needs improvement to achieve a higher level of collaboration across disciplines. These findings suggest that applying and clearly defining procedures aligned with the BIM methodology can significantly contribute to the company's advancement in BIM maturity.

3.4. Opportunities for ISO 19650 Adoption and BIM Integration

The analysis of the company's current practices revealed significant process gaps, particularly in the interactions between the Commercial, Planning, and Project Departments. The absence of well-defined procedures and standardized guidelines has resulted in inconsistent workflows, leading to miscommunication, interdepartmental friction, and ultimately rework and delays in project delivery. These issues hinder effective collaboration across disciplines and compromise the overall efficiency and quality of project outcomes.

In response to these challenges, this dissertation proposes the development of a BIM-based framework tailored to the company's needs, guided by the principles and structure of ISO 19650 - Part 2: Project Delivery Phase. The focus on Part 2 is particularly relevant, as the aim is to enhance the company's project execution capabilities through structured information management and improved cross-functional collaboration during design, coordination, and delivery stages.

ISO 19650 offers a comprehensive framework for managing information across the lifecycle of a built asset. However, it is acknowledged that the standard was developed primarily for large-scale organizations and projects, often involving formal tendering processes and extensive contractual structures. In contrast, the company studied in this research operates as a small to medium-sized enterprise (SME) and does not typically engage in public or competitive tendering. Despite this, many of the principles, workflows, and procedural elements described in ISO 19650 can be adapted to fit the realities and scale of the organization. This dissertation recognizes the need for flexibility in implementation, emphasizing scalability and practical applicability over rigid compliance.

To address the specific gaps identified in the company's processes and organizational structure, the following ISO 19650 components are proposed for adaptation and implementation:

- Process Mapping and Optimization: Digital workflows will be mapped and optimized using ISO 19650 processes as a framework. This will help to align roles and responsibilities with information delivery cycles, while also enhancing communication and collaborative work.

- BIM Execution Plan (BEP): The BEP will clarify roles, tasks, and procedures throughout the project lifecycle, facilitating effective communication between the project team and the client.

- Exchange Information Requirements (EIR): The EIR will establish standardized requirements in collaboration with the MEP subcontractor team, guiding project delivery in terms of models, documents, formats, and data structures.

- Information Delivery Specification (IDS) & Level of Information Need: These tools will structure the EIR by clearly defining the required information, appropriate levels of detail, and delivery timing, ensuring both precision and efficiency.

- Common Data Environment (CDE): A centralized and secure CDE will be implemented to support consistent collaboration, controlled versioning, and efficient exchange of structured project information.

- Classification System: A unified object classification system will be introduced to improve consistency in asset management and support future facility operations.

To summarize and organize the dissertation proposals, a 5W1H Method Table was developed to illustrate the potential applications of ISO 19650 within the company (Table 1). The "Why" component was excluded from the table, as the rationale for these improvements has already been addressed in the dissertation objectives and throughout the discussion on ISO implementation opportunities.

Table 1 – Opportunities for ISO 19650 Adoption and BIM Integration

WHAT	HOW	WHERE	WHO	WHEN
Map BIM Processes	Create updated process maps aligning with ISO 19650 information flow	Internal documentation, BEP	Project Manager and Coordinator with the Delivery Team agreement	During project setup and internal reviews
Define BIM Execution Plan (BEP)	Create a post-contract BEP	At project coordination and execution phases	Project Manager and Coordinator with the Delivery Team agreement	After Commercial Proposal acceptance and before design starts
Define Exchange Information Requirements (EIR)	Develop subcontractor EIR	During project planning and initiation	Project Manager and Coordinator with the MEP subcontractor	In the beginning of the design phase
Establish Common Data Environment (CDE)	Well define the usage and workflow of the cloud-based platform	Across all project phases and disciplines	IT Department and Project Team	Immediate implementation across all projects
Apply Information Delivery Specification (IDS)	Define structured information requirements for MEP Project Deliverables	Design and construction documentation stages	Project Team, MEP subcontractor Leader	At each MEP Project Delivery milestones
Use Level of Information Need	Tables per use case	BEP appendices	Project Team, MEP subcontractor Leader	Before modelling starts
Adopt Classification System	Integrate standardized classification codes into templates and models	Throughout models, deliverables	Project Manager and Coordinator with the Delivery Team agreement	During setup and model development

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4. PROPOSED BIM-BASED IMPROVEMENTS AND IMPLEMENTATION STRATEGY

Following the analysis of the company's current practices and workflows, and the identification of opportunities for ISO 19650 implementation, a set of strategies was developed to enhance the Project Department's operations through a BIM-based framework. The new process maps aimed to foster greater collaboration among stakeholders, boost productivity and efficiency, and support cost-saving initiatives. Subsequently, a prototype object, a parametric wall, was created to evaluate the capabilities of the selected BIM software tools. ArchiCAD (2025) in supporting the customization of prefabricated elements.

Upon completion of this experimental phase, the focus shifted to the development of best practices and formal documentation. A BIM Execution Plan (BEP) was created to standardize the project design process, formalizing the delivery expectations between appointing party (client) and lead appointed party (Kronan). Based on the BEP, an Exchange Information Requirements (EIR) document was formulated to define the expected interactions and deliverables from the MEP subcontractor to Kronan. As part of the EIR, a BIM model validation process was introduced, incorporating the definition of the Level of Information Need and the implementation of the Information Delivery Specification (IDS).

4.1. Collaborative Roles Definition

One of the key definitions introduced by ISO 19650:2018 is the concept of Appointing and Appointed Parties. To illustrate the application of this concept, Figure 22 presents the relationships among the main parties involved in the Redesign–Construction Scope. Within this framework, the client assumes the role of the Appointing Party, responsible for initiating the project. Kronan acts as the Lead Appointed Party, tasked with coordinating both the design adaptation and the overall project delivery, while the architectural, structural, and MEP teams are incorporated as Appointed Parties.

In this contractual arrangement, a second Appointed Party is also present: the Architectural Office responsible for authoring the architectural project. Subsequently, the Architectural Office also has a design delivery team, addressed as Appointed Party as well. This configuration creates a triangular relationship in which the two appointed parties must collaborate to meet the client's requirements. The significance of explicitly defining these parties lies in standardizing communication channels, clarifying deliverables, and delineating responsibilities, ensuring alignment of expectations across all stakeholders.

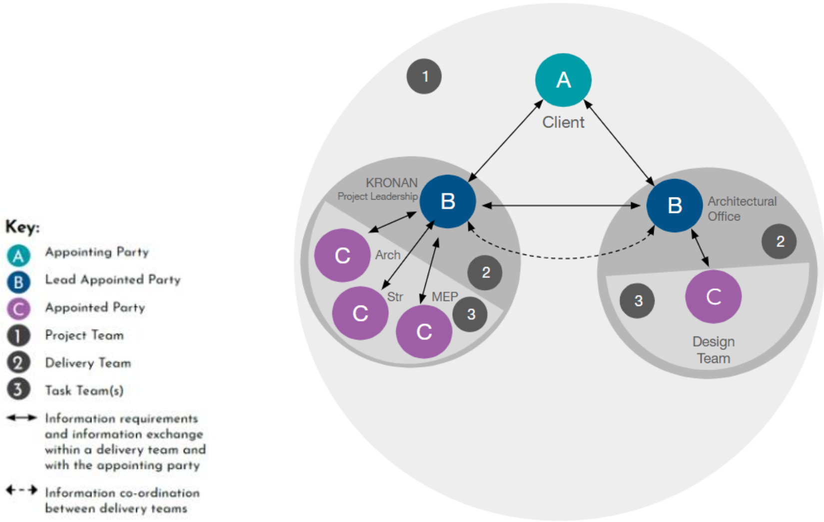


Figure 22 – Kronan's Appointment Parties Diagram

4.2. Redesigned Process Map Using BIM

In redesigning the subprocesses - Modelling for Budgeting and Executive Project Development - focused on the Projects Department workflow, the key considerations included clearly identifying responsibilities, assigning responsible parties, defining the sequence of activities, and specifying the corresponding information exchanges. To develop the TO-BE Process Maps, the document "Information Management According to BS EN ISO 19650: Guidance Part 2 – Processes for Project Delivery", published by the Information Management Initiative (UK BIM Framework, 2021), was used as the primary reference. Both of the subprocesses redesigned are also available in the APPENDIX 04 and 05.

While the redesigned subprocesses were inspired by and aligned with the ISO 19650 (ISO, 2018) standard, certain adaptations were necessary to accurately reflect the company's specific practices and operational scale. Consequently, the tasks outlined in the proposed processes do not correspond exactly to the normative clauses. Nonetheless, the connections between the relevant normative clauses and the redesigned processes are explicitly addressed in the following sections.

4.2.1. TO BE Modelling for Budgeting Subprocess

To make the entire subprocess easier to understand at a readable scale, it was divided into four segments (Figure 23). In order to align the new process with the established project milestones, the stages were designated according to the ISO 19650 framework: Assessment and Need (19650-2 clause 5.1), Appointment (19650-2 clause 5.4), Mobilization (19650-2 clause 5.5), Collaborative Production of Information (19650-2 clause 5.6), Information Model Delivery (19650-2 clause 5.7), and Project Close-Out (19650-2 clause 5.8).

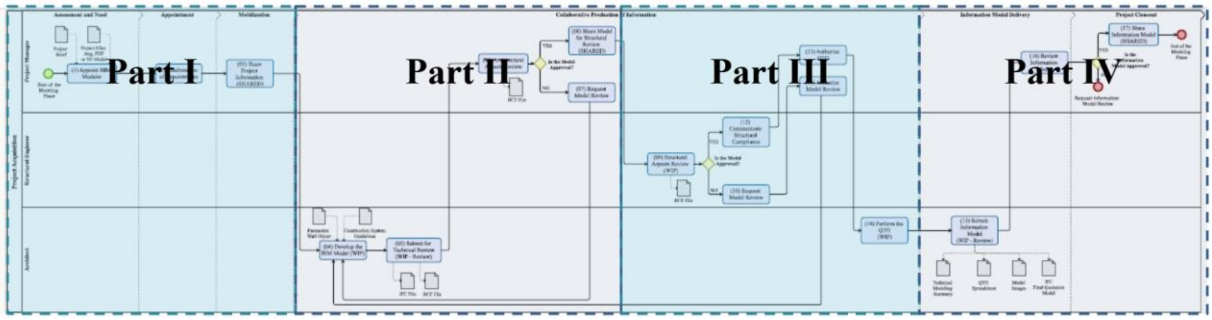


Figure 23 – TO BE Modelling for Budgeting Subprocess – General Overview

The TO BE Acquisition Process Flow consists of (Figure 24, 25, 26 and 27):

<u>Assessment and Need</u>

(1) **Appoint BIM Modeler:** The Project Manager appoints the Architect responsible for the project. The Architect must receive the Project Brief and the project files.

<u>Appointment</u>

(2) **Confirm the deliverables:** The Project Manager confirms the requirements regarding the initial prefabricated solution.

<u>Mobilization</u>

(3) **Share Project Information (SHARED):** The Project Manager configures the project's CDE and share the project information with the Architect.

<u>Collaborative Production of Information</u>

(4) **Develop the BIM Model (WIP):** The Architect Generates information by developing the BIM model in a WIP folder. This represented an alteration in the AS IS Process, when the Project Manager and the Structural Engineer could be responsible for the modelling tasks. This decision was taken to allow the Project Manager to focus on project supervision rather than execution activities. Similarly, the Structural Engineer is excluded to avoid overlapping responsibilities between the processes of project acquisition and execution, which could lead to workload imbalances. To develop the model, the Architect must consult the Construction System Guidelines and use the parametric wall created to optimize the prefabricated requirements checks.

(5) **Submit for Technical Review (WIP - Review):** The architect must submit the IFC file for technical review by the Project Manager and use BCF files for communication.

(6) **Architectural Aspects Review:** the Project Manager performs information model review.

(7) **Request Model Review:** If the model is not aligned with the architectural language of the original project, the Project Manager request model review.

(8) **Share Model for Structural Review (SHARED):** If the model is approved, the Project Manager forwards it for structural review.

(9) **Structural Aspects Review (WIP):** The structural engineer reviews the model.

(10) **Request Model Review:** if the model does not match the structural requirements the engineer request a model review.

(11) **Authorize Model Review:** The Project Manager authorize the model review according to the structural recommendations.

(12) **Communicate Structural Compliance:** if the model matches the structural requirements the engineer communicate structural compliance.

(13) **Authorize QTO:** The Project Manager authorizes the Architect to perform quantity take-off.

(14) **Perform the QTO (WIP):** The Architect performs quantity take-off in a WIP folder.

(15) **Submit Information Model (WIP - Review):** the Architect submits the final files for review: Technical Modelling Summary, QTO Spreadsheet, Model Images and IFC Final Quotation Model.

(16) **Review Information Model:** The project manager verifies the deliverables.

Project Closeout

(17) **Share Information Model (SHARED):** After the Project Manager approves the deliverables, they are share with the Planning Department for Commercial Proposal development, concluding the subprocess.

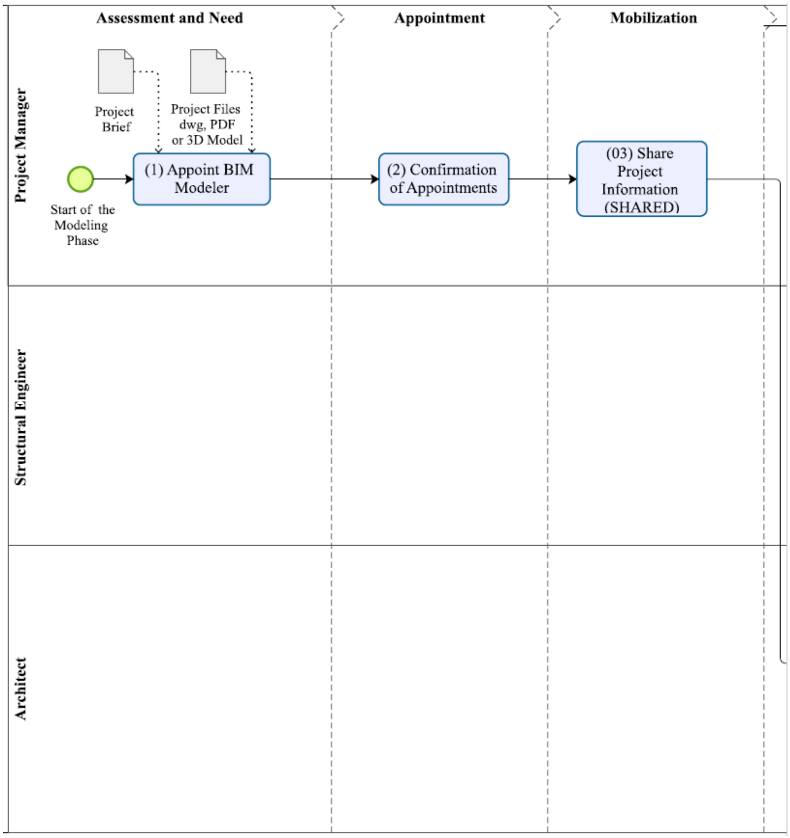


Figure 24 – TO BE Modelling for Budgeting Subprocess - Part I

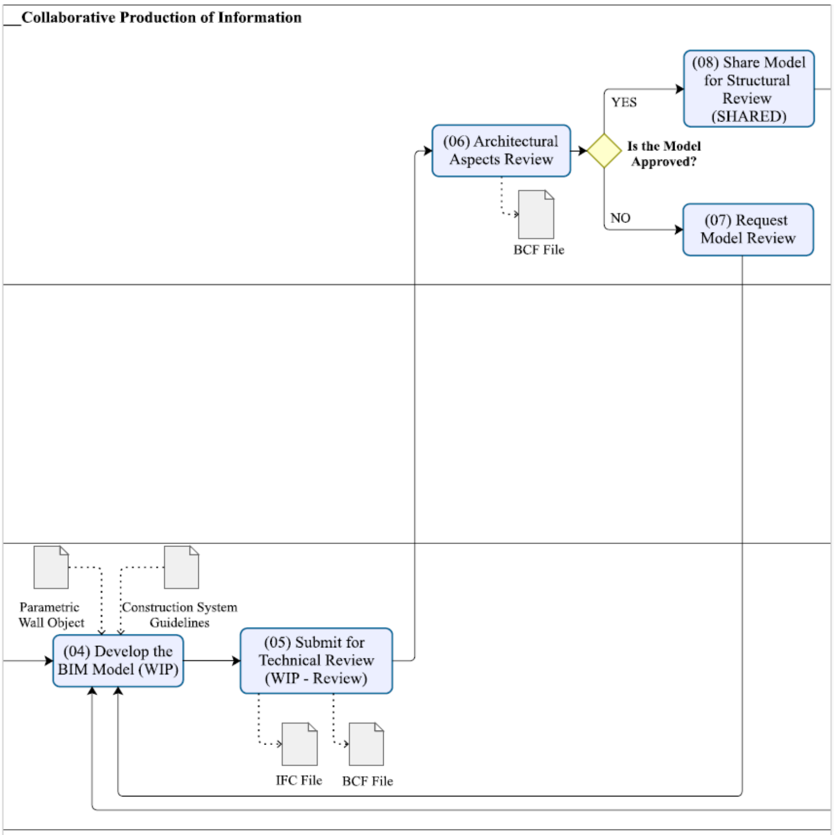


Figure 25 – TO BE Modelling for Budgeting Subprocess - Part II

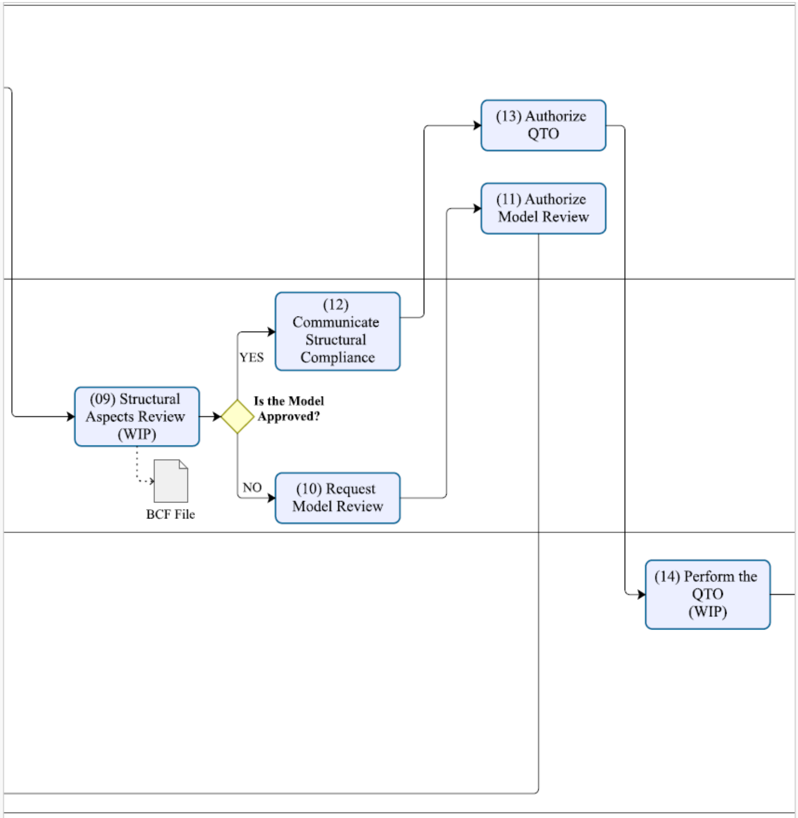


Figure 26 – TO BE Modelling for Budgeting Subprocess - Part III

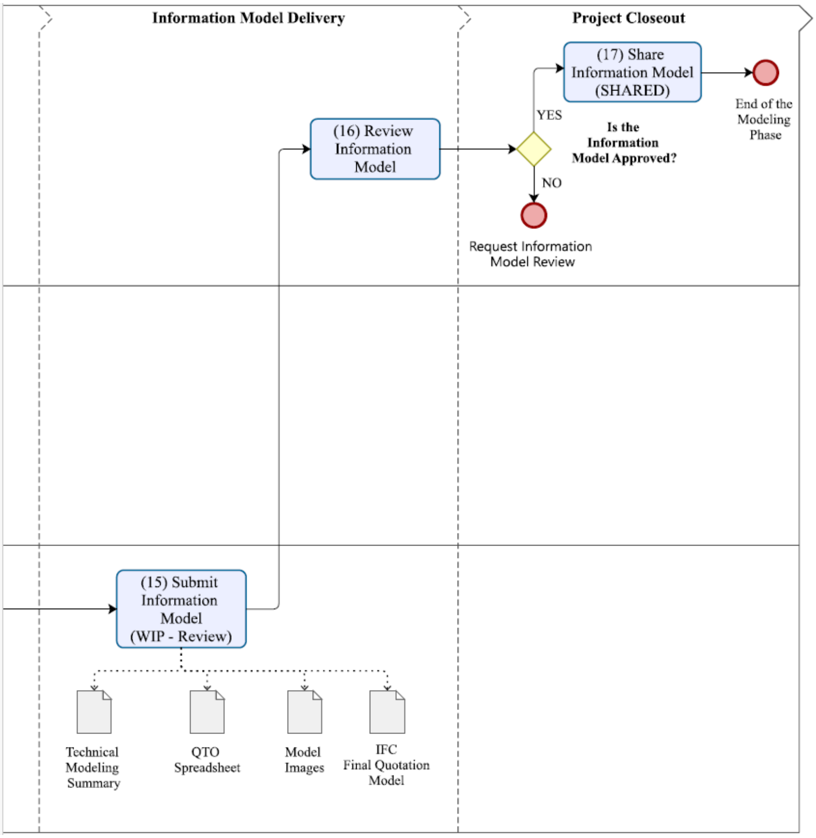


Figure 27 – TO BE Modelling for Budgeting Subprocess - Part IV

4.2.2. Executive Project – TO BE Process Map

For the Executive Project, the process was segmented into nine parts to facilitate an appropriate reading (Figure 28).

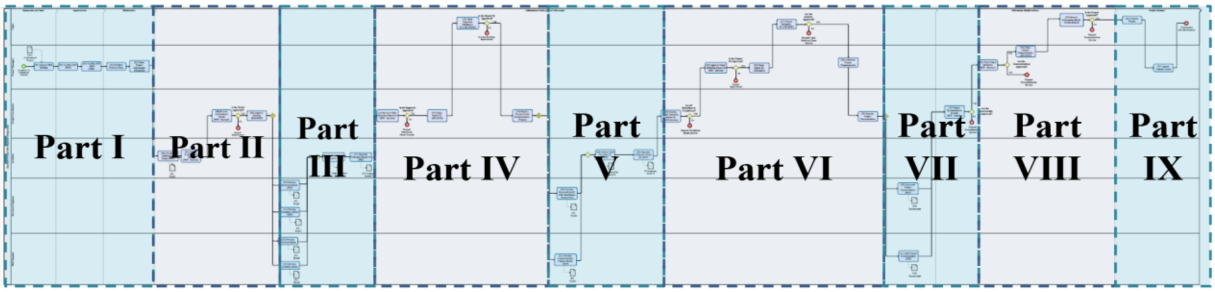


Figure 28 – Executive Project - TO BE Process Map

The TO BE Executive Project Flow consists of (Figure 29 - 37):

<u>Assessment and Need</u>

(1) **Appoint BIM Modeler:** The Project Manager nominates the architect to be responsible for the project.

<u>Appointment</u>

(2) **Confirm BEP (WIP):** The Project Manager elaborates the BEP based on the template.

(3) **Confirm EIR – MEP (WIP):** The Project Manager elaborates the EIR dedicated to the MEP subcontractor. According to the ISO 19650, the EIR also should be developed for the relation between Kronan (Leader Appointed Party) and client (Appointing Party), but usually the client does not have maturity knowledge about the AEC in general. Therefore, in this redesign subprocess was chosen to develop only the EIR for MEP.

<u>Mobilization</u>

(4) **Mobilize Delivery Team:** Project Manager mobilize the delivery team to start the work.

(5) **Share Project Information (SHARED):** The Project Manager share the BEP, the EIR and the Project Information with the delivery team.

<u>Collaborative Production of Information</u>

(6) **Develop Architectural Model (WIP):** The Architect replicates the final executive architectural project, verifying that all required information is present. If there are any uncertainties, the architect should contact the external architectural office for clarification.

(7) **Submit Architectural Model (WIP- Review):** Once the model is completed, it is submitted for the Project Coordinator's review.

(8) **Review Architectural Model (WIP- Review):** The Project Coordinator validate the architectural model or request for model review.

(9) **Approve Sharing (SHARED):** The Project Coordinator shares the approved architectural model with the other disciplines.

(10) **Develop Structural Model (WIP):** The Structural Engineer develop the concrete panel model.

(11) **Develop Foundation Model (WIP):** The Foundation Engineer develop the discipline model

(12) **Develop Electrical Model (WIP):** The subcontractor team develop the Electrical Model.

(13) **Develop Hydraulic Model (WIP):** The subcontractor team develop the Hydraulic Model.

(14) **Perform Clash Detection 01 (WIP):** The Architect performs the first clash detection after receiving the discipline models.

(15) **Generate Federated Model 01 (WIP):** The Architect generates the first federated model.

(16) **Review Clash Detection Report 01 (WIP - Review):** The Project Coordinator executes the first model review by checking the clash detection and executing IDS verification.

(17) **Share Report 01 (SHARED):** Once approved, the Project Coordinator shares the clash detection report with the client.

(18) **Clash Detection Validation I (PUBLISHED):** The client must communicate the model validation or request for model review.

(19) **Require Structural and Complementary Projects:** Once approved, The Project Coordinator requires the development of the Structural and Complementary Projects.

(20) **Develop Structural Model with Installation Points:** Once the first federated model is approved, the structural engineer develops the discipline model with the installation points assembly.

(21) **Develop Complementary Projects Model (WIP):** in case of complementary projects need, the federated model is shared with the external supplier for modelling.

(22) **Perform Clash Detection 02 (WIP):** The Architect performs the second clash detection after receiving the discipline models.

(23) **Generate Federated Model 02 (WIP):** The Architect generates the second federated model.

(24) **Review Clash Detection Report 02 (WIP – Review):** The Project Coordinator executes the second model review by checking the clash detection and executing IDS verification.

(25) **Approve Clash Detection Report 02 (WIP – Review):** The Project Manager must approve the federated model to share with the client for final approval.

(26) **Share Report 02 (SHARED):** The Project Manager the federated model and the report with the client for final approval.

(27) **Project Validation (PUBLISHED):** The client analyses the federated model and the report for final approval.

(28) **Authorize Project Documentation:** With the positive answer of the client, the Project Manager authorize the documentation phase.

(29) **Require Project Documentation:** The Project Coordinator communicates the documentation phase to the delivery team and align with them the final delivery workflow.

(30) **Structural Project Documentation (WIP):** Structural engineer creates the discipline documentation.

(31) **MEP Project Documentation (WIP):** MEP subcontractor creates the discipline documentation.

Information Model Delivery

(32) **Project Documentation Review (WIP - Review):** The Project Coordinator reviews the deliverables.

(33) **Final Project Validation (WIP - Review):** the Project Manager validates the deliverables.

(34) **Share Project Documentation (SHARED):** the Project Manager shares the final documentation with the client.

(35) **Review the Information Model (PUBLISHED):** The client validates the project documentation for the last time.

Project Closeout

(36) **Archive Project:** The client archives the files for construction site mobilization.

(37) **Capture Lessons Learnt:** The Project Manager captures lessons learnt from the project for future works.

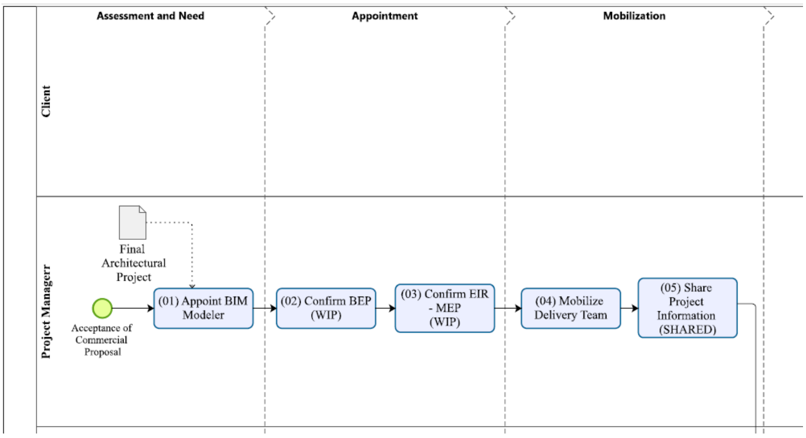


Figure 29 – TO BE Executive Project Development Subprocess Map - Part I

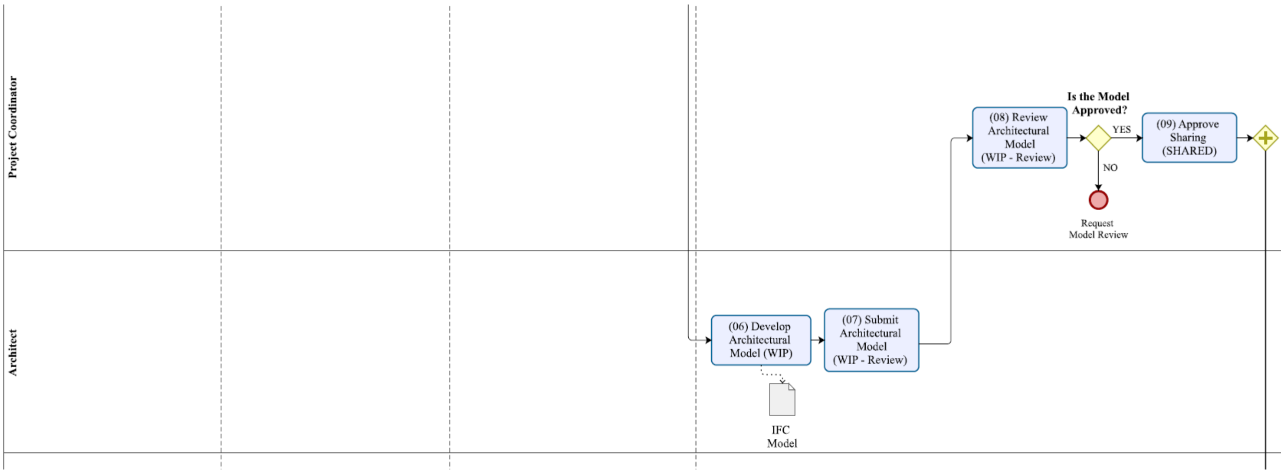


Figure 30 – TO BE Executive Project Development Subprocess Map - Part II

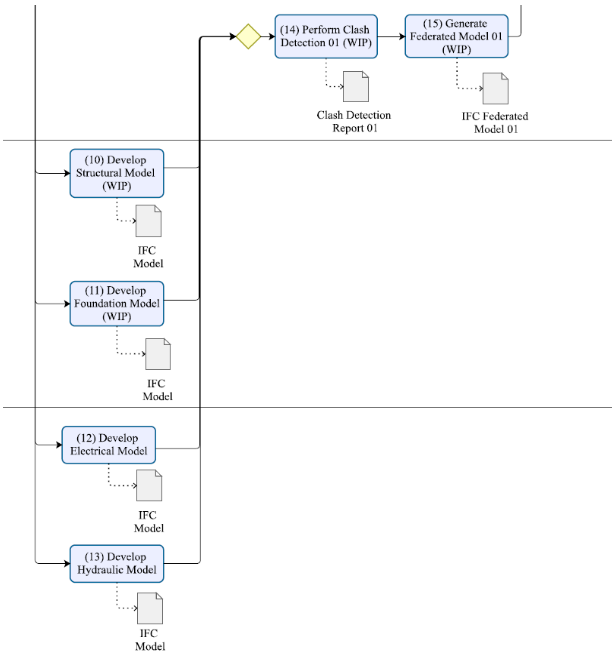


Figure 31 – TO BE Executive Project Development Subprocess Map - Part III

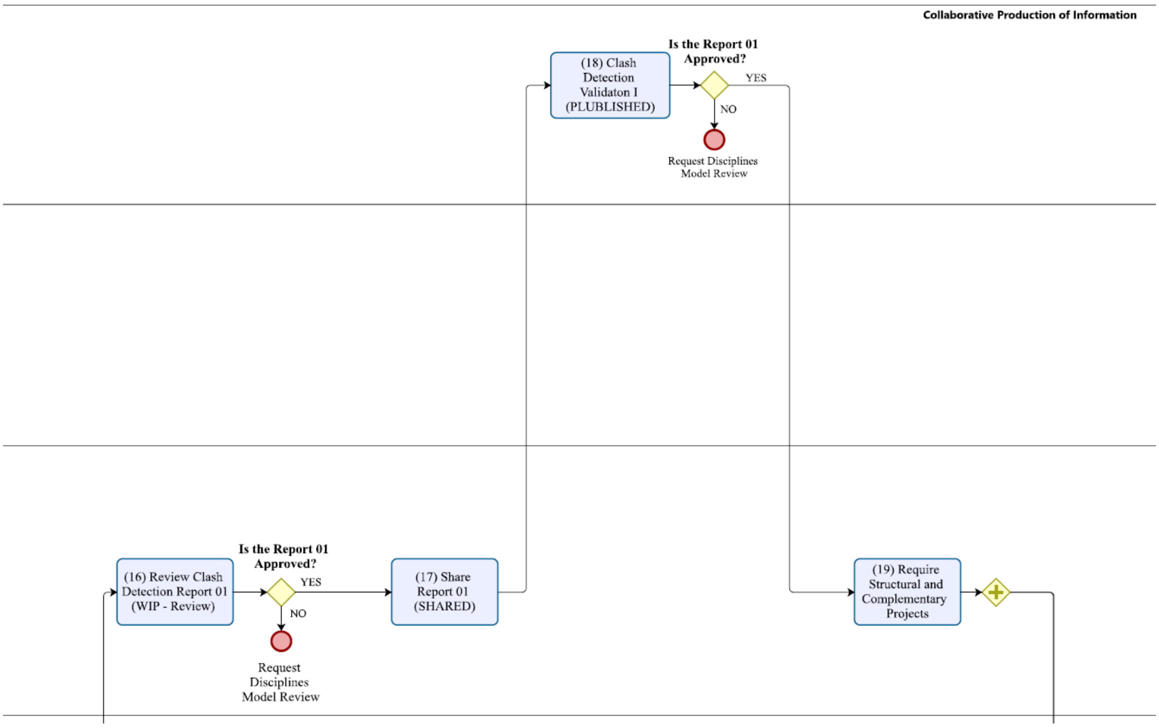


Figure 32 – TO BE Executive Project Development Subprocess Map - Part IV

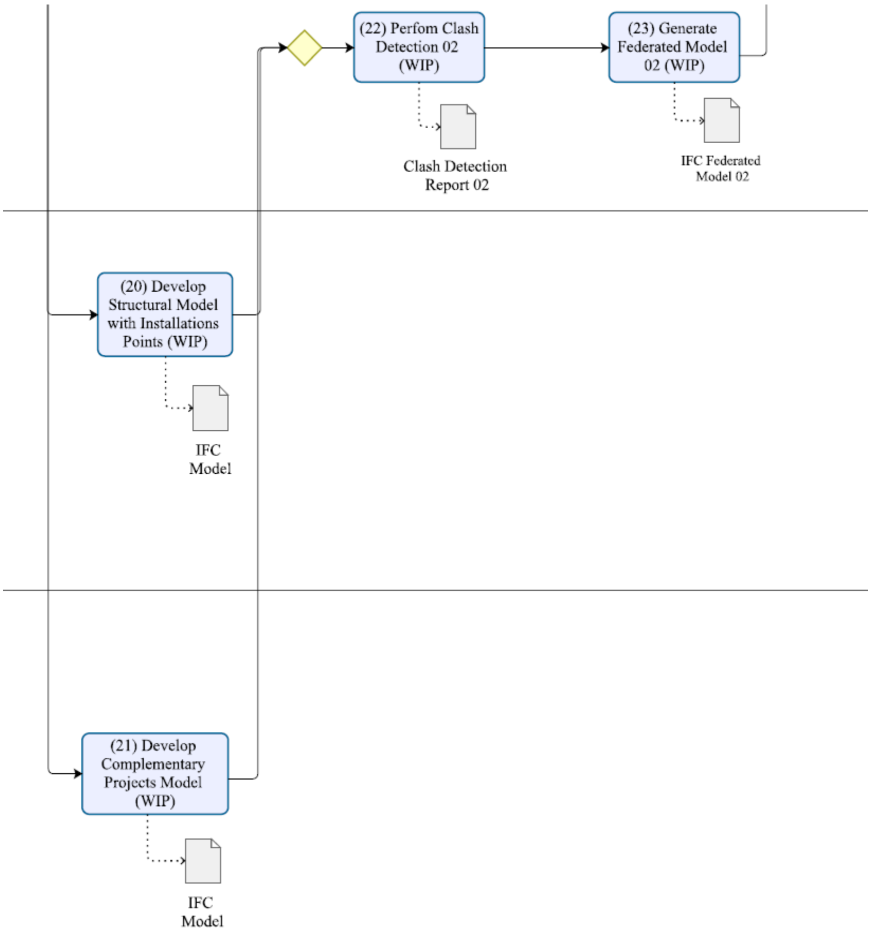


Figure 33 – TO BE Executive Project Development Subprocess Map - Part V

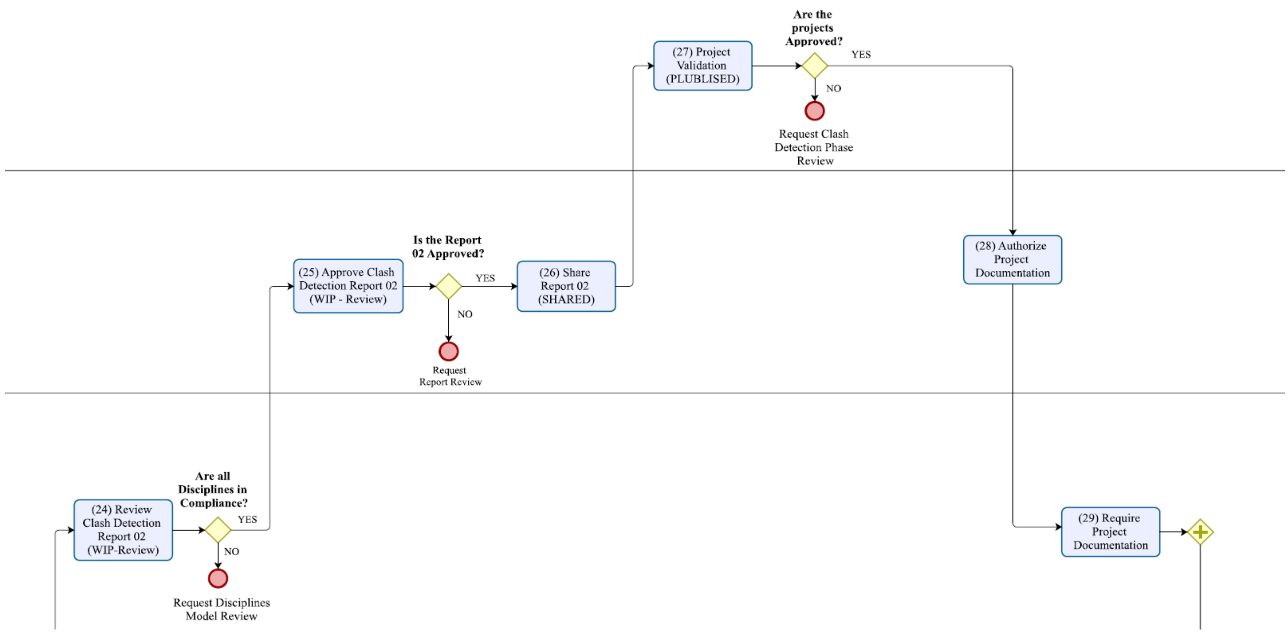


Figure 34 – TO BE Executive Project Development Subprocess Map - Part VI

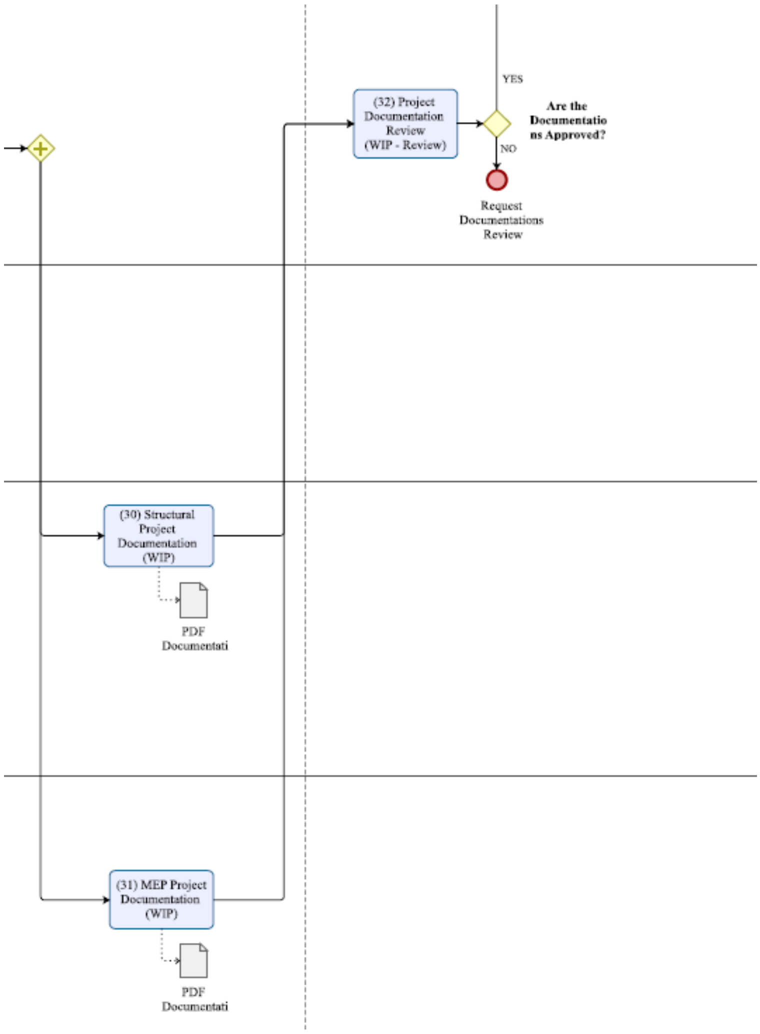


Figure 35 – TO BE Executive Project Development Subprocess Map - Part VII

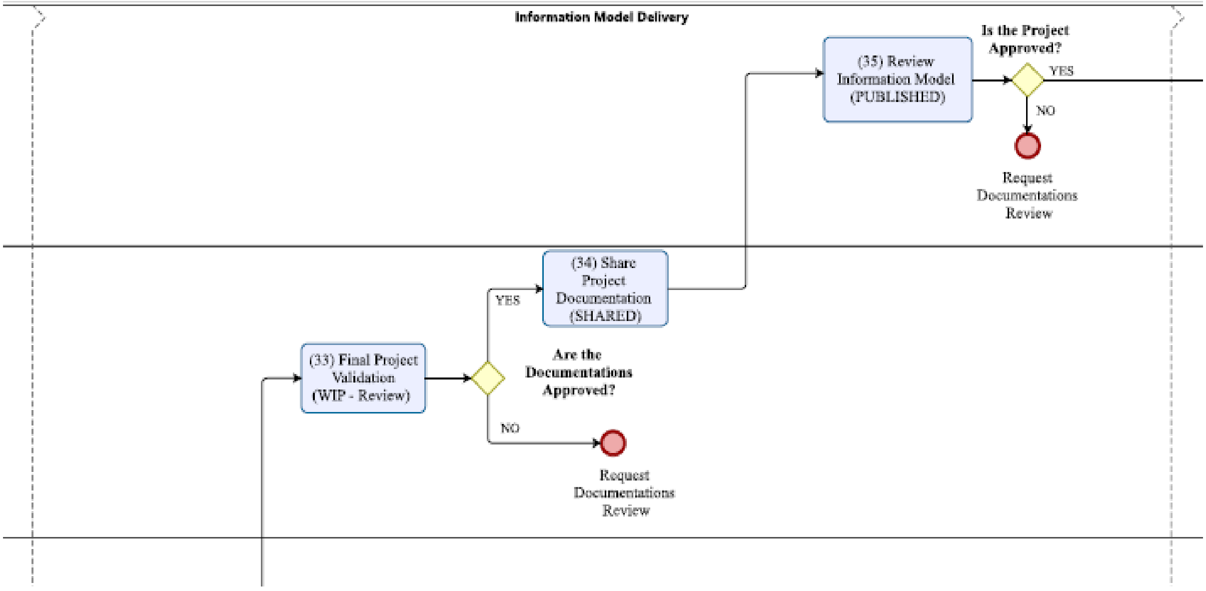


Figure 36 – TO BE Executive Project Development Subprocess Map - Part VIII

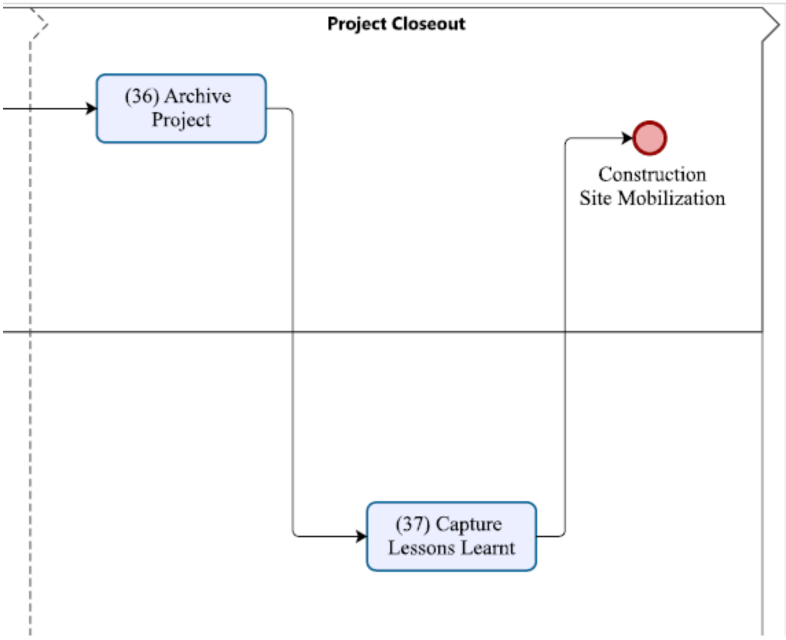


Figure 37 – TO BE Executive Project Development Subprocess Map - Part IX

The main improvements introduced in the TO-BE process are the inclusion of the foundation and structural models in the first clash detection phase, rather than waiting until the second. This allows incompatibilities between disciplines to be detected earlier, including issues related to panel wall dimensions and hollow-core slabs. In addition, were introduced the BEP and EIR as protocols, the CDE workflow and the model validation using IDS files. Finally, the introduction of partial approval of the model by the client between the first and the second clash detection, aided in avoiding rework after the clash detection phase conclusion.

4.3. Parametric Object for Cost Estimation

Following the redesign of the process maps, the research moved into a more experimental phase. This stage involved proposing a parametric object aimed at optimizing the Modelling for Budgeting subprocess, while simultaneously establishing constraints and rules for the insertion of openings. To determine the rules for the parametric object, the parameters were defined as follows (see Figure 38):

1- **Maximum Length (1) and height (2) panel definition -** the first rule to be created was to limit the maximum length and height dimensions of the object according to the measurements of the concrete forms available at the company's factory.

2- **Panel thickness -** the parameter is the panel thickness restriction which the user could only select the predefined patterns.

3- **Number of openings –** it was defined the minimum and the maximum number of openings that one panel is suitable to fit.

4- **Distance from the borders (3)** – this is the most important definition for the panels, because to ensure panel structure stability is necessary to define the minimum distance of the borders creating a proportion between the opening width and this minimal distance.

5- **Distance between openings (4)** – minimal distance between the openings is mandatory to guarantee the structural function of the panel.

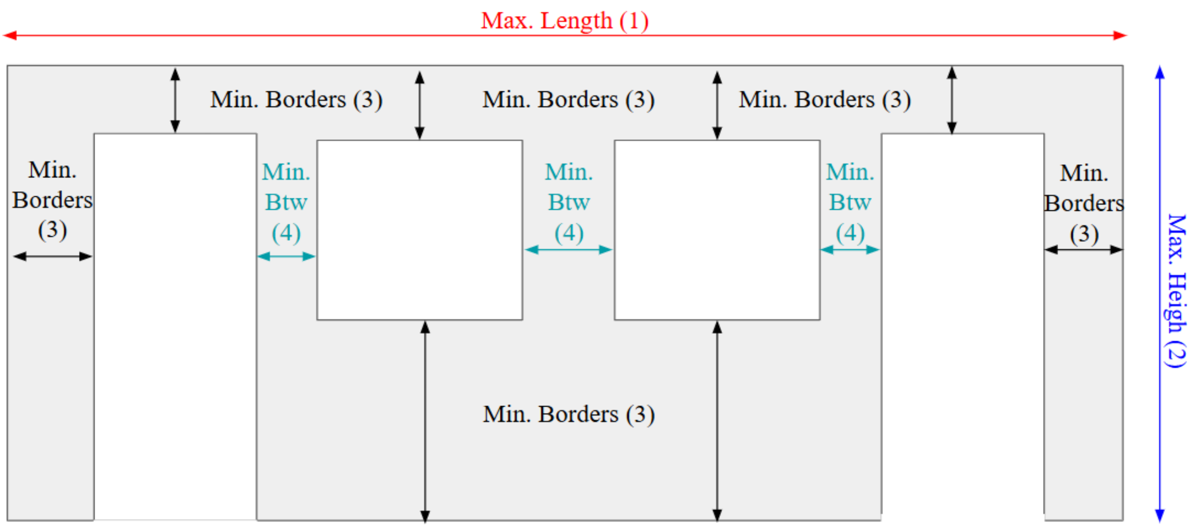
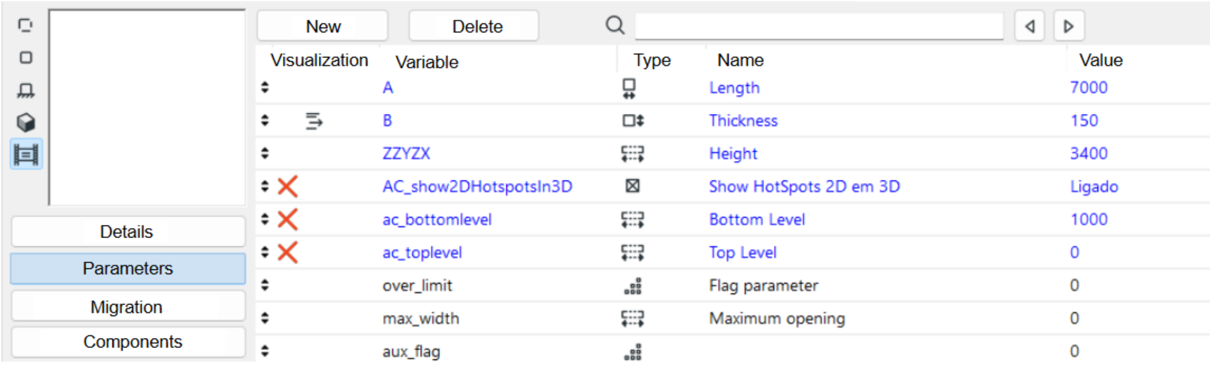


Figure 38 – Desirable Parameters for Control

To create the five controlling principles, the GDL (Geometric Description Language) of ArchiCAD was explored, allowing the development of new parametric objects. The first step involved inserting variables to define the wall's length, height, and thickness, along with control points known as Hotspots (Figure 39).

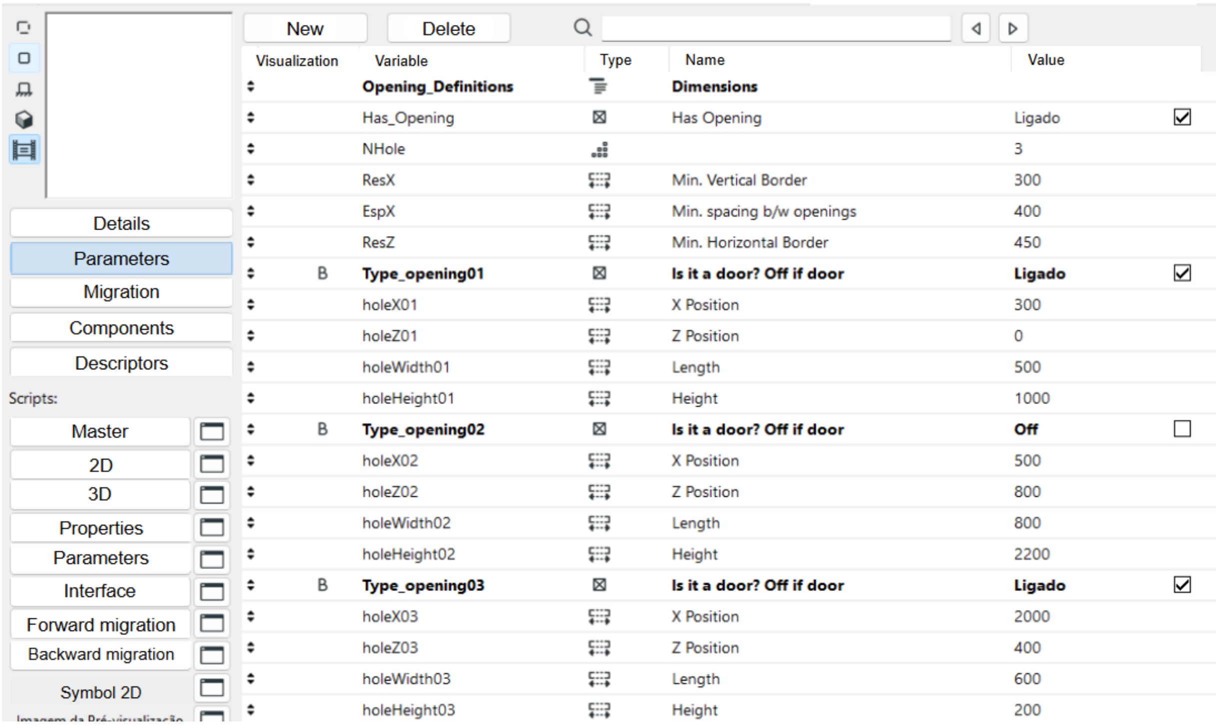


Visualization	Variable	Type	Name	Value
	A		Length	7000
	B		Thickness	150
	ZZYZX		Height	3400
	AC_show2DHotspotsIn3D		Show HotSpots 2D em 3D	Ligado
	ac_bottomlevel		Bottom Level	1000
	ac_toplevel		Top Level	0
	over_limit		Flag parameter	0
	max_width		Maximum opening	0
	aux_flag			0

Figure 39 – Wall's parametric variables

After establishing the wall dimensions, additional variables were defined to control the dimensions of the openings (Figure 40). A Boolean parameter named Opening_Definitions was created, enabling users to specify whether the wall includes openings. This was followed by parameters for defining the number of openings, the minimum distance from the wall edges, and the required spacing between openings.

Once the relationship between the wall and the openings was established, parameters were created to define the size and position (in the X and Z axes) of each opening. For each opening, a Boolean parameter named Type_opening was implemented to differentiate between doors and windows. This distinction is essential: if the opening is a door, no distance from the lower edge of the wall is needed. However, for windows, a minimum distance from the bottom of the wall must be maintained to ensure structural stability.



Visualization	Variable	Type	Name	Value
	Opening_Definitions		**Dimensions**	
	Has_Opening		Has Opening	Ligado ☑
	NHole			3
	ResX		Min. Vertical Border	300
	EspX		Min. spacing b/w openings	400
	ResZ		Min. Horizontal Border	450
B	**Type_opening01**		**Is it a door? Off if door**	**Ligado** ☑
	holeX01		X Position	300
	holeZ01		Z Position	0
	holeWidth01		Length	500
	holeHeight01		Height	1000
B	**Type_opening02**		**Is it a door? Off if door**	**Off** ☐
	holeX02		X Position	500
	holeZ02		Z Position	800
	holeWidth02		Length	800
	holeHeight02		Height	2200
B	**Type_opening03**		**Is it a door? Off if door**	**Ligado** ☑
	holeX03		X Position	2000
	holeZ03		Z Position	400
	holeWidth03		Length	600
	holeHeight03		Height	200

Figure 40 – Openings' parametric variables

After defining the parameters that would be controlled by the user, the scripting phase began. This phase involved creating logical rules to constrain parameter values and prevent dimensional errors during object generation.

In GDL (Geometric Description Language), scripts are written in two main windows. The primary one is called the Master Script Window. Its purpose is to define shared data, global variables, and preliminary calculations required by other script sections (such as 2D, 3D, and Parameters). It executes before all other scripts and sets the foundation for consistent behaviour across the object (Graphisoft, 2025).

Within the Master Script, constraints were defined for the wall panel's length, height, and the number of openings (Figure 41). Conditional logic using control structures such as IF, THEN, and ELSE was then implemented to manage the allowable width of the openings and their placement along the wall (Figure 42 and Figure 43). These conditions ensure that the user-defined values remain within structurally and visually valid range.

To ensure the accurate placement of openings, users must insert the first opening starting from the left side of the wall and proceed to the right. A second opening can only be inserted after the first one has been correctly placed. If the user inputs dimensions that exceed the allowed limits, the result will be the omission of that element during generation.

In the 3D Script Window, the wall panel's material was defined as concrete, and the geometry of the panel was created using the BLOCK function, which generates a rectangular solid (Figure 44). Additionally, if the user attempts to input wall dimensions that exceed the predefined limits based on the factory's formwork capabilities, the program automatically adjusts the values to the maximum permissible dimensions.

```
! Restrict Dimensions
! Wall's length
IF A < 0.3 THEN A = 0.3
IF A > 8.0 THEN A = 8.0
! Wall's height
IF ZZYZX < 0.3 THEN ZZYZX = 0.3
IF ZZYZX > 3.39 THEN ZZYZX = 3.39
! Restrict number of openings in the wall
IF NHole < 1 THEN NHole = 1
IF NHole > 3 THEN NHole = 3
```

Figure 41 – Defining Wall Dimensions restrictions

```
! Restrictions for positioning the openings
FOR i=1 TO NHole
    IF i=1 THEN
    ! X Position
        IF (VholeX[i] < ResX)  THEN
        VholeX[i] = ResX
        ENDIF
    ! Z Position
        IF Type_opening[i] THEN
        ! It is a window, therefore should worry about the height
            IF  VholeHeight[i] > (ZZYZX - 2.0*ResZ) THEN
                VholeHeight[i] = ZZYZX - 2.0*ResZ
            ENDIF
            IF (VholeZ[i] < ResZ)  THEN
                VholeZ[i] = ResZ
            ENDIF
        ELSE
            IF  VholeHeight[i] > (ZZYZX - ResZ) THEN
                VholeHeight[i] = ZZYZX - ResZ
            ENDIF
            VholeZ[i]=0.0
        ENDIF
    ELSE
    ! X Position
        IF (VholeX[i] < (VholeX[i-1]+EspX+VholeWidth[i-1]))  THEN
        VholeX[i] = VholeX[i-1]+EspX+VholeWidth[i-1]
        ENDIF
    ! Z Position
        IF Type_opening[i] THEN
        ! It is a window, therefore should worry about the height
            IF  VholeHeight[i] > (ZZYZX - 2.0*ResZ) THEN
                VholeHeight[i] = ZZYZX - 2.0*ResZ
            ENDIF
            IF (VholeZ[i] < ResZ)  THEN
```

Figure 42 – Part I: Defining Openings Dimensions restrictions

```
            ENDIF
        ELSE
            IF  VholeHeight[i] > (ZZYZX - ResZ) THEN
                VholeHeight[i] = ZZYZX - ResZ
            ENDIF
            VholeZ[i]=0.0
        ENDIF
    ENDIF
    ! Updating values
    VholeX[i] = VholeX[i]
    VholeZ[i] = VholeZ[i]
    VholeWidth[i] = VholeWidth[i]
    VholeHeight[i] = VholeHeight[i]
NEXT i

! Calculate total width of openings
total_length = ResX + HoleWidth01 + EspX + HoleWidth02 + EspX + HoleWidth03 + ResX

! Check if the openings are too big for the wall
IF total_length > A THEN
    over_limit = 1
    max_width = A - ResX + HoleWidth01 + EspX + HoleWidth02 + EspX + ResX
ELSE
    over_limit = 0
ENDIF
! Check if each opening is well positioned
FOR i=1 TO NHole
    IF (VholeX[i]+VholeWidth[i])>(A-ResX) THEN
        aux_flag = i
    ENDIF
NEXT i
```

Figure 43 – Part II: Defining Dimensions openings restrictions

```
!Fill, Material and Surface Definitions
MATERIAL gs_fill_type
MATERIAL gs_wall_concrete
MATERIAL gs_wall_mat

!OPENINGS
IF Has_Opening THEN
    FOR i = 1 TO NHole
! Cut each opening from the wall
        ROTX 90
        mulz 0
        CUTPOLY 4,
            VholeX[i], VholeZ[i],
            (VholeX[i] + VholeWidth[i]), VholeZ[i],
            (VholeX[i] + VholeWidth[i]), (VholeZ[i] + VholeHeight[i]),
            VholeX[i], (VholeZ[i] + VholeHeight[i]),
            1,1,1
        DEL 1
        DEL 1
    NEXT i
ENDIF
!Painel Dimensions
!BLOCK a, b, c (comprimento, espessura, altura)
BLOCK A, B, ZZYZX
CUTEND
```

Figure 44 – Wall 3D Geometry

By embedding these parameters, the system guides users during the modelling process, ensuring that any design inputs comply with predefined dimensional limitations. This approach supports the preliminary sizing of precast concrete panels, enhancing both design consistency and constructability. The interface created to the user it is possible to set the dimension parameters for each opening and the distance between them (Figure 45).

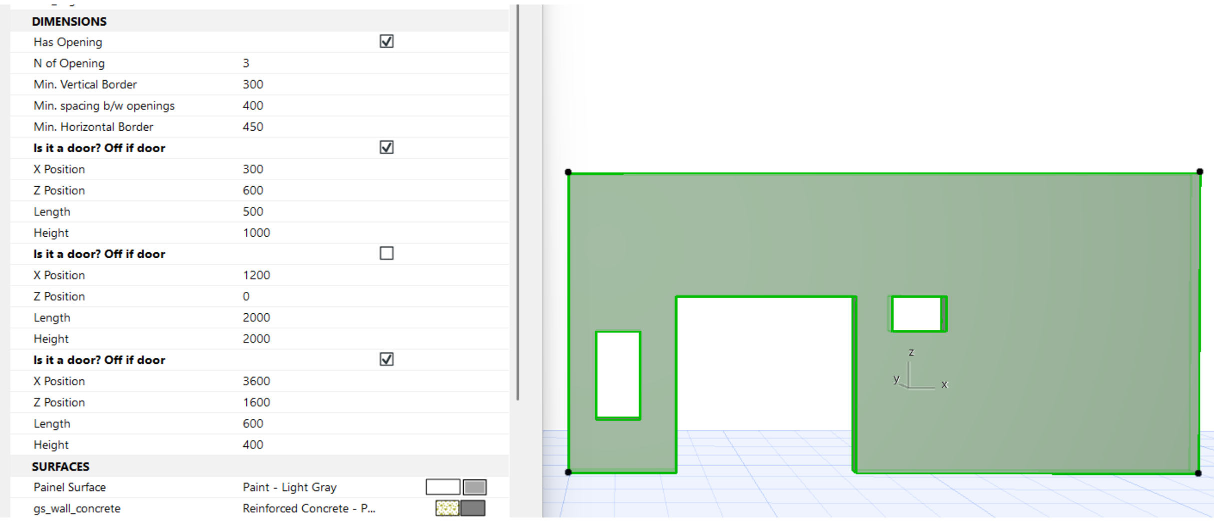


Figure 45 – Wall Parameters Definition

4.4. BIM Execution Plan Development

To structure project phases, define key stakeholders and milestones, and centralize critical project information, a Post-Contract BIM Execution Plan (BEP) was developed. A future Pre-Contract BEP should use the same structural principles outlined here with appropriate adaptation to it the context.

4.4.1. Scope and Project Overview

The opening section of the BEP defines the scope and objectives of the document and the project itself. This helps ensure that all stakeholders can immediately grasp the intent and structure of the BEP. Following this, the document provides a general overview of the project, including its name, location, delivery methodology, size, timeline, and contract type. For this case study, the selected contract type was “Redesign-Construction Scope”, which aligns with the company's strategic and operational context. To visualize the full document developed, consult APPENDIX 6.

4.4.2. Stakeholders and Communication Structure

A Contact List (APPENDIX 6) is included to identify key stakeholders, their contact details, and project roles from the beginning of the project, to avoid future misunderstandings or misalignments. This information is fundamental for establishing clear communication channels and defining responsibilities throughout the project lifecycle.

In the sequence, the BEP outlines the Project Milestonesv (APPENDIX 6), which describe the project’s development timeline, from the initial design phase through federated model coordination to final documentation. A section on BIM Uses (APPENDIX 6) defines the specific applications of BIM throughout the design and construction process, emphasizing the importance of standardized procedures in ensuring consistent, high-quality outcomes.

4.4.3. Roles and Responsibilities

The Responsibility Matrix proposed (APPENDIX 6) in this work defines how responsibilities are distributed across the project team for each deliverable, following the Responsible, Accountable, Consulted, and Informed (RACI) framework (PMI, 2013). This matrix is closely aligned with the design process map phase, as the updated process map must incorporate clearly defined responsibilities for each task and ensure transparency throughout the approval stages.

For instance, responsibility for the BIM Execution Plan (BEP) is shared between the Project Manager and BIM Coordinator, while task team members are identified as consulted parties. This structured approach ensures that the project timeline aligns with team capacity and availability, while also promoting a collaborative and transparent project environment. The subsequent tasks carried out in this study were intended to demonstrate the complexity and interdependence inherent in collaborative project workflows.

4.4.4. Workflow and Information Requirements

Linked with the roles and responsibilities section, the Process Map (APPENDIX 5) illustrates the workflow to be followed by the Project Team throughout the project lifecycle. It serves as a visual aid to help team members understand the sequence of actions and their roles in the broader workflow.

To evaluate, check and standardize the deliverables during the Project Executive Process addressed to the subcontracted MEP team, the Exchange Information Requirements (EIR) (APPENDIX 7) and Level of Information Need (APPENDIX 9) were defined. These tables define the minimum requirements concerning the modelling, data quality, and information delivery, aligning expectations between the contractor and sub-contractors.

4.4.5. Information Delivery and Collaboration

The Master Information Delivery Plan (MIDP) outlines the timing and responsibility for all major project deliverables. It ensures that activities remain aligned with project deadlines, reducing risks associated with delays and miscommunication. A key section of the BEP is Collaboration Procedures, which defines the digital workflows that facilitate teamwork. This includes specifications for the Common Data Environment (CDE), organized into Work in Progress (WIP), Shared, and Published folders in line with ISO 19650 (ISO 19650:2018) recommendations.

To address common issues in traditional folder structures, particularly the inability for disciplines to collaborate on incomplete files, this BEP proposes the creation of a collaborative WIP folder. This folder allows the Architectural, Structural, and MEP teams to share files and exchange feedback before formally submitting them for approval. The goal is to reduce reliance on informal communication tools (e.g., messaging apps) and encourage structured collaboration directly within the CDE through IFC files and BCF workflows. In addition to folder organization, the BEP defines a file naming convention based on ISO 19650-2 (ISO 19650-2:2018), which is critical for document traceability and consistency across the project lifecycle.

4.4.6. Meetings and Communication

To ensure consistent decision-making, the BEP outlines meeting procedures, including types, frequency, participants, and the mandatory implementation of meeting minutes. Formalizing these procedures ensures that key project decisions are recorded and that all parties, including the client, are aligned in terms of responsibilities and expectations. the content of the meetings must also be aligned with the project milestones highlighted in the Project Executive Process Map.

4.4.7. Modelling Procedures and Quality Control

The Modelling Procedures section of the BEP defines the classification system used to tag model elements, based on the ABNT NBR 15965 (ABNT, 2022) standard in Brazil. This standard supports the categorization of BIM elements according to attributes such as function and materiality. Modelling criteria are established to ensure model completeness and quality control, particularly during federated coordination. The BEP also defines the coordinate system and units, specifying Brazil's official spatial reference system (EPSG:31983 – SIRGAS 2000) and the International System of Units (SI). This avoids scale inconsistencies and misalignments between models.

To conclude, the BEP includes a Clash Detection Matrix and a Quality Control Checklist, which together define the key validation steps required to assess the BIM model’s readiness. The Clash Detection Matrix was developed to simplify and filter the combinations of disciplines that must be checked, enabling efficient use of the clash detection automation features available in the selected BIM software. It sets out practical verification rules and defines tolerances for both hard and soft clashes, resulting in a precise and objective coordination report.

The Quality Control Checklist (APPENDIX 6) serves as a practical tool for verifying compliance with project requirements, modelling standards, and applicable regulations prior to model delivery. In addition to these two quality control tools, the checklist also incorporates the use of IFC (Industry Foundation Classes) files, ensuring model interoperability across different software platforms. Furthermore, it includes the application of IDS (Information Delivery Specification) files, which are based on the project's Level of Information Need tables. These IDS files are used to confirm that each model includes the minimum required information, supporting both quality assurance and compliance with information requirements defined in the EIR.

4.5. Definition of the Exchange Information Requirements

To guide the development of the Exchange Information Requirements (EIR), the document's scope was first clearly defined, ensuring a structured approach to selecting and organizing its contents. The EIR (APPENDIX 7) outlines the minimum information requirements to be met by the MEP team throughout the design phase, with a focus on ensuring full coordination with architectural and structural disciplines. The structure and content of this EIR were informed by the example developed by BuildingSMART Portugal and aligned with the ISO 19650 framework, ensuring international compliance ((buildingSMART, 2024).

The structure of the EIR begins with the definition of Organisational Information Requirements (OIR), which are tailored to align with KRONAN’s Mission, Vision, and Values. These requirements are essential to ensure that information production directly supports strategic business goals such as innovation, operational excellence, regulatory compliance, and cost-effectiveness throughout the asset lifecycle. By anchoring the OIR in strategic principles, the information delivered during the project contributes not only to technical accuracy but also to broader organizational priorities.

Following the OIR, the EIR specifies the Project Information Requirements (PIR). These focus on the specific information needs of the project, including its scope, key phases, and decision points. The PIR structure ensures that information is delivered in a timely manner to support tasks such as clash detection, cost estimation, and regulatory validation. The decision to organize the EIR in alignment with the same contract type used for the BEP, namely the manufacturing and assembly of prefabricated panels, was intended to maintain consistency between contractual deliverables and information management practices.

To consolidate and operationalize the information requirements, a detailed Table of Requirements was developed. This table links each PIR objective to its corresponding EIR items, clearly defining what information is required at each design phase, from the modelling of the site context to the final delivery of project documentation. In addition, the EIR adopts and expands upon the acceptance criteria established in the BEP, offering more detailed guidance on data handling, CDE usage, and compliance with security protocols. This structured approach not only supports project coordination and BIM interoperability but also ensures that the MEP team delivers information aligned with both regulatory standards and the appointing party’s expectations.

4.6. BIM Model Validation: Level of Information Need, IDS, and Clash Detection

BIM model validation is the process through which the quality and completeness of information in a model are verified. Traditionally, this has been carried out using requirement tables derived from the BEP and EIR documents. However, these protocols are typically written in human-readable language, which limits the potential for automation and consistency checks using digital tools. To bridge this gap between human and machine interpretation, this study proposes the use of Level of Information Need tables in combination with the Information IDS standard to verify the presence and adequacy of information within IFC files across disciplinary models.

The primary objective of this validation process is to ensure that the model contains the necessary data to support accurate quantity take-offs and material specifications for construction. For each discipline (architecture, structure, and MEP), the Level of Information Need tables define the purpose of the required information according to the current project phase. These phases range from early conceptual design analysis to final stages involving detailed drawings, 3D coordination, quantity extraction, and cost estimation.

The Level of Information Need (APPENDIX 9) framework distinguishes between geometric and alphanumeric requirements. Minimum geometric information includes aspects such as size, shape, dimensions, location, and appearance. Alphanumeric information, on the other hand, pertains to the presence of key metadata such as object classification, attributes, property sets, materials, and compliance with a classification system. The IDS standard is then applied to validate the presence and structure of these alphanumeric elements within the IFC schema.

For the classification system, this work adopts the ABNT NBR 15965 (ABNT, 2022) standard, which serves as the national reference for the classification of BIM objects in Brazil. The use of a standardized classification system ensure consistency across different models and interoperability during information exchange among stakeholders.

In addition to information validation, the clash detection was also performed to verify geometric interferences between model elements and disciplines. This process was divided into two categories: hard clashes, where two objects occupy the same space, and soft clashes, which means the insufficient mandatory spatial distance between two elements. The concept underpinning this project was the development of a clash detection matrix designed to objectively define which elements and disciplines should be cross-checked. The primary objective was to ensure that the matrix remained practical and user-friendly, avoiding excessive length and an overabundance of comparison lines. Overly detailed matrices, while comprehensive, often result in reduced efficiency, increased complexity in coordination processes, and a higher likelihood of inconsistencies. Such characteristics ultimately hinder their applicability in real-world project environments, particularly in multidisciplinary coordination settings. As part of the validation workflow, clash detection complements the use of Level of Information Need and IDS by addressing spatial coherence.

5. PILOT PROJECT FOR BIM IMPLEMENTATION

After redesigning the project department's two core processes and implementing ISO 19650–based tools tailored to the case study company, a pilot project (Figure 46) was launched to simulate the proposed framework. This chapter illustrates how key BIM management instruments, such as the BIM Execution Plan (BEP), Exchange Information Requirements (EIR), Information Delivery Specification (IDS), Level of Information Need, and clash detection protocols, can improve both model quality and design workflow efficiency.

The pilot serves as a controlled environment to assess the benefits, limitations, and challenges of BIM-based processes. By testing and validating the methodology in practice, the study provides clearer insights into its potential for broader application. Additionally, the case study enables systematic evaluation of collaboration, model coordination, and information exchange across disciplines.

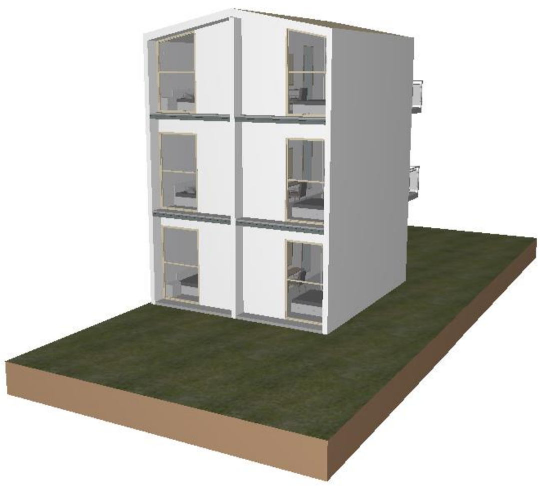


Figure 46 – Pilot Project view

5.1. Scope and Objectives of the Pilot Project

The location of the project was chosen with consideration of a potential real-world opportunity, as it is situated near the State University of Campinas (UNICAMP). UNICAMP is one of the most prestigious universities in Brazil, attracting students from different regions of the country as well as from abroad, which creates a consistent demand for student housing. The selected site is located within a five-minute walking distance from one of the main entrances of the campus, the UNICAMP Clinical Hospital (HC-UNICAMP). This strategic location provides convenient access both to the university and to the major highways surrounding the city, making it highly suitable for the proposed development (Figure 47).

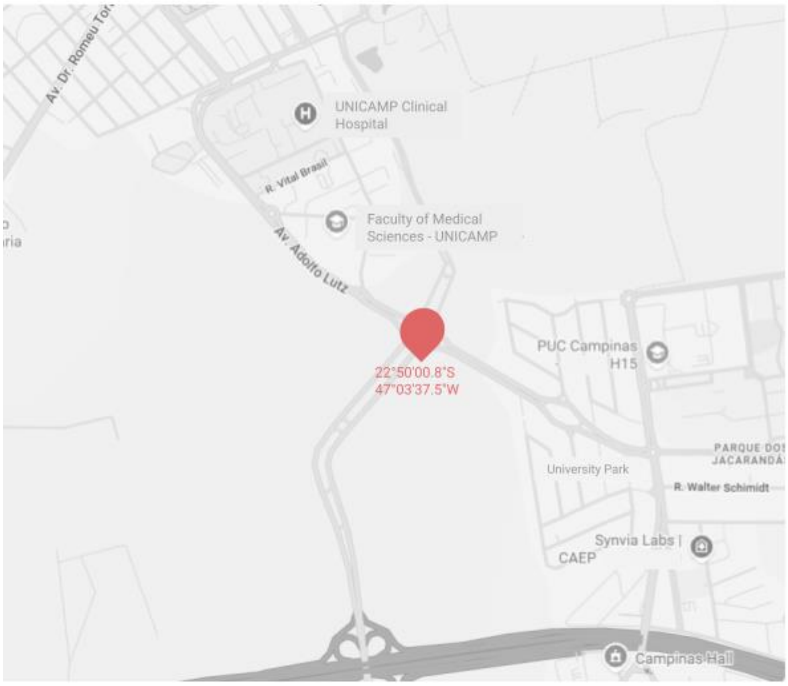


Figure 47 – Pilot Project location.

The project, named Study HOUSE, carries the Project Number 241 and Project Code SHE. It adopts the contract type "manufacturing and assembly of prefabricated panels", with a total project size of 174.36 m², distributed across three floors (two housing units per floor). Each unit includes one bathroom, one kitchen, and one bedroom (Figure 48). The external walls are designed with precast concrete panels, while the internal partitions are made of drywall.

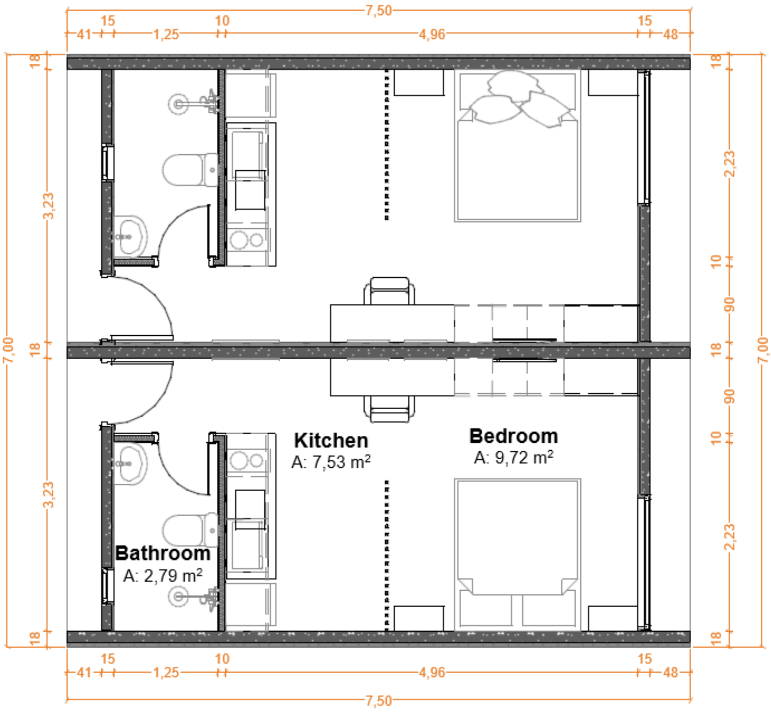


Figure 48 – Typical floor plan

It is important to highlight that the project is fictional, created exclusively for the purpose of this research. The decision to simulate this project, rather than adopt a real one, stems from the specific contract modality chosen. A real prefabricated panel project would require the involvement of an external architectural office, which could lead to copyright implications and intellectual property constraints. To simplify the process and allow a complete and autonomous exploration of the BIM methodology, a fictional project was designed to serve as a representative case study for BIM implementation.

5.2. Application of the BIM Modelling Framework

To simulate the BIM Modelling Workflows described in detail in the previous chapter, the two TO BE process maps were tested: the Acquisition Project and the Executive Project. Both workflows begin with the insertion of the basic project information, such as client name, project name, and location.

For the Acquisition Project, georeferencing the model and defining the true north are not mandatory, nor is the inclusion of land morphology. This decision reflects a common situation in which clients do not yet possess complete site survey data, such as topographic surveys or soil drilling reports, which could otherwise create barriers to the initial proposal development. Nevertheless, it is important to emphasize that when such information is available, its incorporation significantly increases the precision of the proposed budget. For the Executive Project, all the project information previously mentioned are mandatory.

5.2.1. Acquisition Project Workflow

To simulate the acquisition project workflow, the architectural design was modelled using the parametric wall object developed in the previous chapter (Chapter 4, Section 4.2) as the external walls of the building, while an object class of drywall partitions was applied for the internal walls (Figure 49). Hollow-core slabs and the roof were modelled using objects available in the ArchiCAD’s standard template. A generic topography element was also created to represent the site.

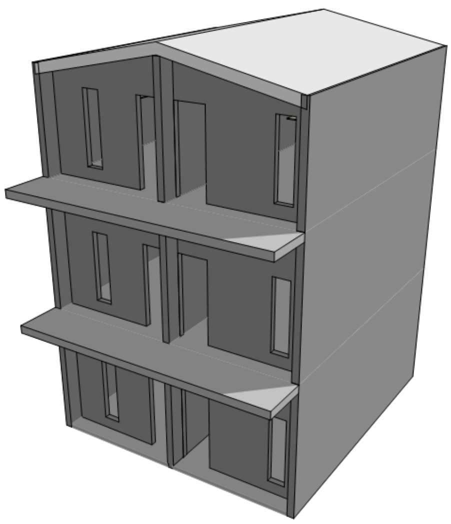


Figure 49 – Test application of the developed parametric wall

The model was first submitted for an architectural review, followed by a structural review in a Common Data Environment (CDE) platform. Communication between stakeholders was facilitated through the use of BCF files. The architect's BCF file included a screenshot, viewpoint, description, and links to IFC elements, addressing modelling uncertainties and proposing alternative design solutions (Figure 50). The Project Manager and the Structural Engineer responded to these queries, after which the project was authorized for the quantity take-off phase.

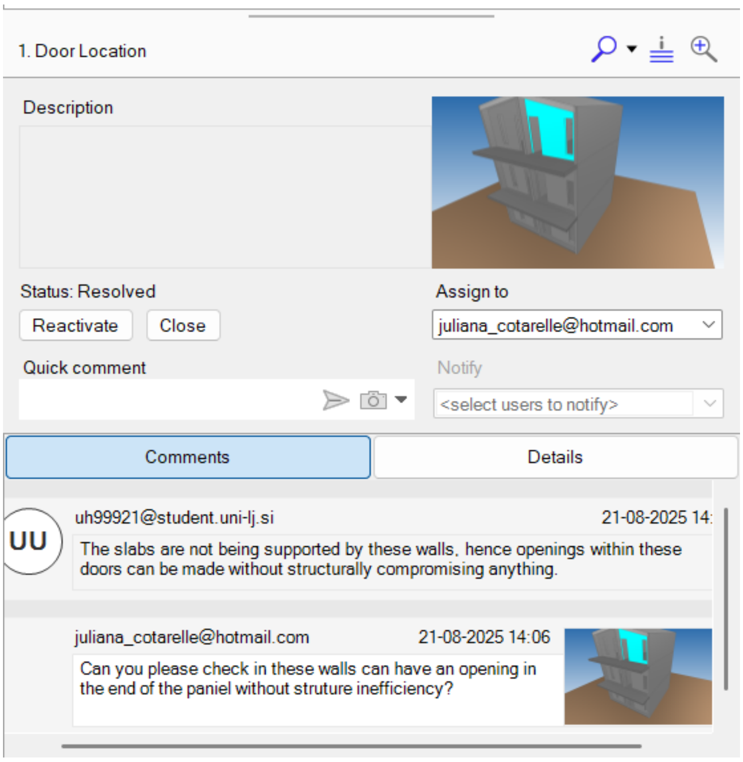


Figure 50 – Team communication through BFC files

During the quantity take-off phase, a new template for the quantity schedules was developed. This template included key attributes such as panel ID, classification, length, height, area, and volume. At the end of each schedule, totals for length, height, area, volume, and number of units were provided. In addition to the schedules, a Technical Modelling Summary, model visualizations, and the final IFC quotation file were produced.

As the primary objective of this model was to prepare an initial commercial proposal for a potential client, the Level of Information Need was intentionally kept low. The model, therefore, included only the essential architectural and structural elements required for preliminary visualization: precast panel walls, internal drywall partitions (or placeholder partitions of undefined material), hollow-core slabs, and the subfloor. Wall openings were represented as simple voids, without details such as frames or finishes. Structural components, including beams and steel columns, were also modelled. At this stage, the parametric wall object developed by the author was implemented and tested, demonstrating its effectiveness in supporting rapid design iterations.

5.2.2. Executive Project Workflow

For the application of the Executive Project Workflow, the first step was the development of the BEP (Appendix 6) and the EIR for the MEP subcontractor team (Appendix 7). Following the EIR, Level of Information Need tables were created to support the modelling process standardization and the development of IDS files for model checking. In addition, a clash detection matrix was produced to validate the compliance of the disciplinary models.

The workflow began with the development of a detailed architectural model, which included topography and project georeferencing, wall elements with frames and opening types, furniture and equipment, electrical, hydraulic, and sanitary points, roof design, and finishing materials. One limitation of the parametric wall object developed was that it was not possible to insert the opening typologies in the same way as with a native wall in the BIM platform. To address this issue, after the acquisition project processes, the architect assigned to the project had to remodel the walls, this time incorporating a refined Level of Information Need and including the appropriate opening typologies.

Afterward, the complementary discipline models (structural, foundation, electrical, and hydraulic) were developed, and the first clash detection was carried out at this stage. Although simplified due to the fictional nature of the project, client approval was included in the workflow to maintain process consistency. A second clash detection followed, now considering installation points embedded in the precast panels. Finally, the process concluded with the documentation phase, where the coordinated model supported the generation of drawings and schedules.

During the workflow, the folder structure and hierarchy of the CDE system were tested. The structure was organized by project, and within each project folder, three main categories of access were created: Work in Progress, Shared, and Published. Within the Work in Progress area, each discipline had its own folder, along with a common folder called WIP – Review, where each discipline maintained a subfolder for submissions requiring review by the Project Manager and Coordinator. This hierarchy was designed to be easily accessible, minimize bureaucracy, and preserve the collaborative nature of the team (Figure 51).

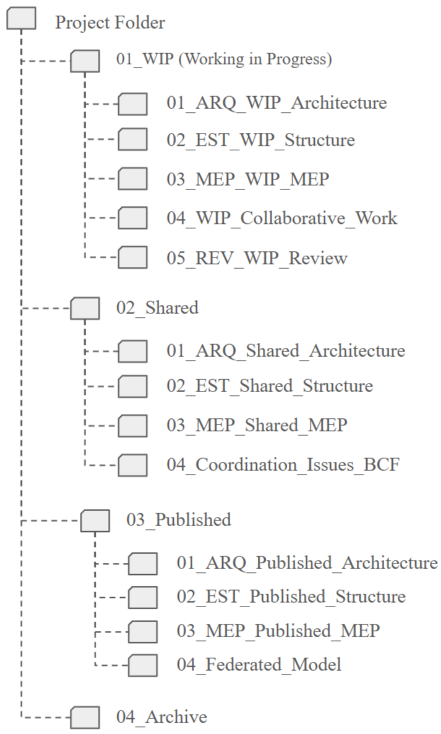


Figure 51 – Folder structure and hierarchy of the CDE system

Although the team had already started using the CDE system in earlier projects, this workflow enabled the consistent application of the principles of the UK BIM Framework and ISO 19650. The main difficulty encountered was client participation in the Published environment, since many clients are more familiar with traditional document-sharing tools (Google Drive, Dropbox, OneDrive, WhatsApp, Telegram, or email). To address this, the IT department created client logins and enabled access through the mobile application of the chosen CDE system.

The implementation of BCF files for communication presented challenges, as the team was accustomed to traditional workflows using online meetings and written reports with annotated images. Introducing the BCF workflow was an initial attempt that needs improvement to become a consistent habit within the team. Nevertheless, BCF files cannot fully replace meetings, since complex issues often involve multiple disciplines and require in-depth discussion. For the first clash detection, a traditional meeting was held with the client, project coordinator, architect, and discipline leaders to clarify problems and allow the client to provide input on proposed solutions. For the second clash detection, communication was handled exclusively through BCF files, as most issues had already been resolved. This eliminated the need for a meeting and saved time for the teams.

Finally, georeferencing workflows were tested across different BIM platforms. The process of georeferencing models was carried out in both ArchiCAD and Revit, and alignment between the models was verified using the BIM Collab Zoom software (Figure 52).

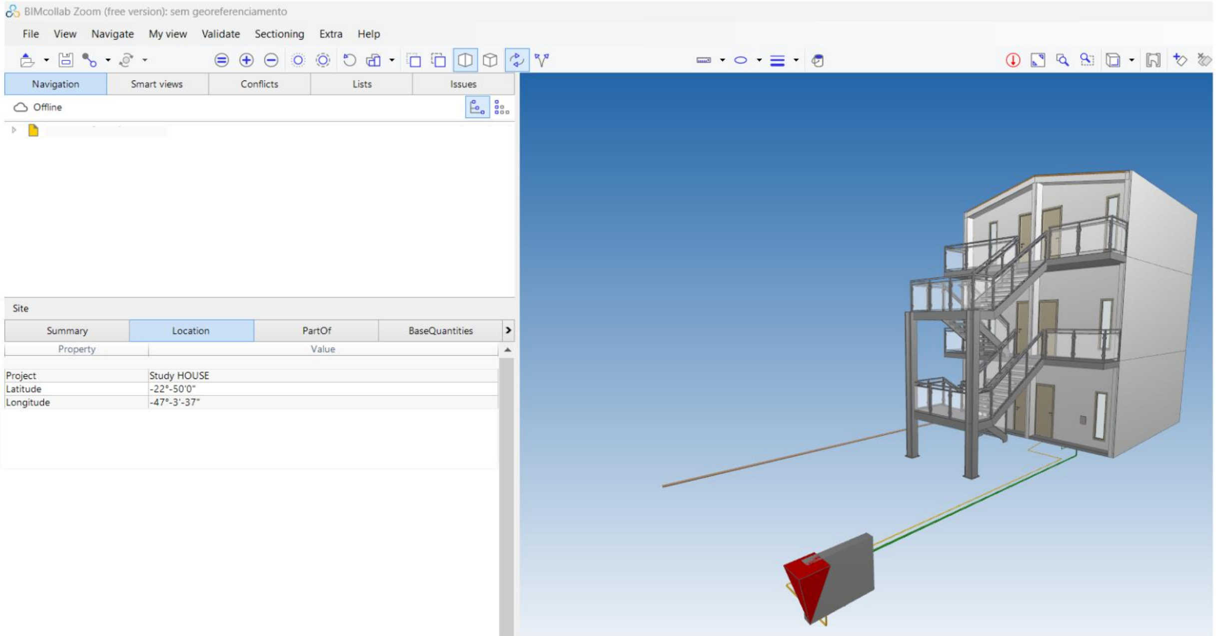


Figure 52 – Federated Model alignment checked through BIM Collab software

5.3. Clash Detection and Issue Resolution

5.3.1. Clash Detection Matrix Context and Development

The clash detection procedure, conducted exclusively within the company's Executive Project Workflow, is a critical phase to ensure compliance and coordination among the discipline models. In previous projects, coordination was primarily conducted through visual inspection during interdisciplinary meetings, subsequently documented in narrative reports containing annotated images. To enhance visual review, colour filters were assigned to each discipline and element transparencies were used when needed after model overlay. However, the absence of consistent georeferencing practices frequently resulted in misaligned models and discrepancies in floor level definitions, increasing the complexity of model preparation.

To address these recurrent challenges, a common georeferenced setup was defined, and a shared 3D reference object (an inverted pyramid) was introduced placed at a common control point across all models. This methodological adjustment significantly reduced the time required for manual alignment while simultaneously improving both the accuracy and repeatability of the clash detection process.

In order to develop a tailored clash detection matrix adapted to the company's project typology, a hierarchical system of discipline precedence was first established (Figure 53). The base of all projects in the company is the architectural project, followed by the structural elements. Within this hierarchy, the architectural model was defined as the foundational reference, followed by structural elements. Subsequent disciplines were ordered according to their relative ease of modification: disciplines with higher flexibility for design changes were situated at the upper levels of the hierarchy, thus assigned lower priority in terms of spatial precedence.

Figure 53 – System Hierarchy

The resulting clash detection matrix (Figure 54) was designed to systematize the verification process by defining both the sequence of discipline comparisons and the appropriate clearance requirements. Its formulation was informed by a focused review of academic literature and professional practice, considering matrices used in industry tools, such as Autodesk, Bexel Manager and Solibri, and professional forums (Autodesk, 2024; BEXEL Manage, 2024; Solibri, 2024). Given the typical scale of the company's projects (single-family housing and low-rise buildings), highly granular matrices were deemed unnecessarily complex and time-consuming. Instead, the elements were grouped by discipline to produce a concise, practical matrix aligned with project scope, while retaining the established discipline colour filters that must be applied in the models in accordance with the matrix (Figure 55). Furthermore, recommended clearance values between disciplines were specified to enhance coordination and reduce the potential for spatial conflicts.

	ARCHITECTURAL	STRUCTURAL (panel, beam and column)	STRUCTURAL (floor and slab)	STRUCTURAL (foundation)	MECHANICAL (HVAC)	PLUMBING (sanitary)	PLUMBING (hydraulic)	ELECTRICAL (light and energy)	ELECTRICAL (LPS)	ELECTRICAL (photovoltaic)
ARCHITECTURAL										
STRUCTURAL (panel, beam and column)	H									
STRUCTURAL (floor and slab)	H	H								
STRUCTURAL (foundation)	H	H	H							
MECHANICAL (HVAC)	H	H	H	H						
PLUMBING (sanitary)	H	H	H	H	C - 100					
PLUMBING (hydraulic)	H	H	H	H	C - 100	C - 50				
ELECTRICAL (light and energy)	H	H	H	H	C - 150	C - 300	C - 300			
ELECTRICAL (LPS)	H	H	H	H	H	H	H	H		
ELECTRICAL (photovoltaic)	H	H	H	H	H	H	H	H	H	

Figure 54 – Clash matrix design

Figure 55 – Colour filters by discipline

5.3.2. Clash Detection Procedure and Outcomes

The clash detection procedure was tested to validate its implementation by following the steps outlined below:

1. **Model preparation and georeferencing**: A shared coordinate system was agreed for all disciplines, and the common 3D reference object (the inverted pyramid) was inserted at the control point in each model. Story levels and model origins were verified to prevent misalignment between floors.

2. **Importation of discipline models and configuration of visibility filters:** Discipline-specific models were imported into the BIM platform through the IFC files. Translator settings were configured according to the native platforms of each discipline to preserve semantic richness and object attributes during import. To facilitate model organization, a dedicated folder structure was established to separate discipline layers from the architectural base model, reducing the risk of overlap or misinterpretation. Each imported layer was then linked to its predefined discipline-specific colour filter, as outlined in the Clash Matrix, enabling rapid visual differentiation and streamlined coordination. At this stage, a preliminary verification of model integrity was conducted to confirm data consistency, geometry accuracy, and adherence to the information requirements defined in the exchange protocols.

3. **Definition of clash criteria:** Within the clash detection tool, element groups were combined pairwise in accordance with the discipline relationships defined in the clash matrix. Tolerance settings were specified for interactions between electrical, sanitary, and hydraulic infrastructures (Figure 56).

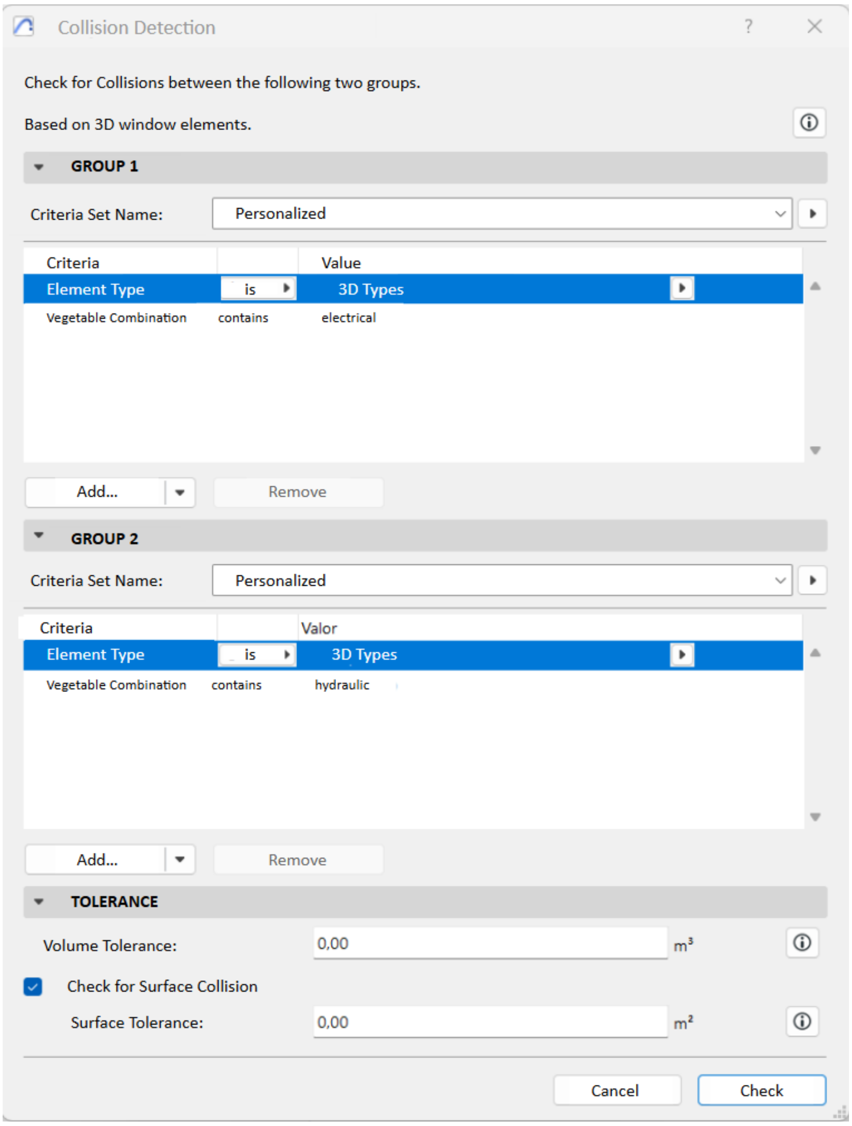


Figure 56 – Definition of clash criteria

4. **Execution of the 1st clash run**: The first collision check was carried out according to the priority order established in the clash matrix. A model check report was generated, including a tabulated list of identified clashes and their graphical representation within the 3D model using visual markers.

5. **Issue registration and responsibility attribution:** Detected clashes were categorized by severity, and each issue was assigned to the responsible discipline. Exported BCF files, containing viewpoints and screenshots, were distributed to the respective task teams (Figure 57). As previously noted, the optimization of clash detection did not fully eliminate the need for coordination meetings, particularly in cases where complex, multi-disciplinary issues arose or where client input was required to define the final solution. To formalize the procedure, a comprehensive clash detection report was produced in PDF format, consolidating all issues identified during the analysis.

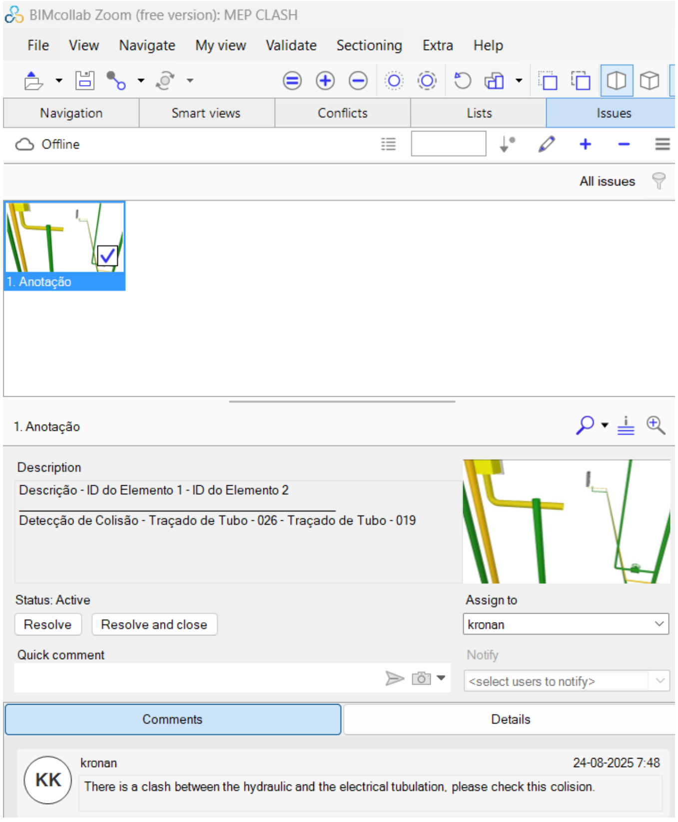


Figure 57 – Communication trough BFC files applied for Clash Detection

6. **Discipline-side corrections:** Each discipline adjusted its model according to assigned issues and tolerances.

7. **Re-coordination and 2nd clash run:** Corrected models were re-published to the shared environment, and Steps 2–5 were repeated.

8. **Close-out and documentation:** A final verification confirmed that all previously registered clashes had either been resolved or appropriately justified. The clash detection report was updated, and a final coordination summary was compiled. The coordinated model was then prepared for documentation, including drawings and tables. At this stage, the execution of an additional coordination meeting was unnecessary, as communication and issue management were conducted entirely through BCF files.

During the use of the clash detection tool, only elements located on visible layers were included in the analysis. This allowed the selective filtering of elements to be considered in each specific clash detection task, avoiding the inclusion of overlapping elements not involved in the coordination process. In this context, it was often possible to refine the scope of detection, for example, by specifying whether hydraulic clashes should consider exclusively horizontal or vertical segments.

Regarding collision typologies, the classification of clashes as either hard or soft proved useful in identifying inconsistencies among the sanitary, hydraulic, and electrical disciplines. It is important to note that the Clash Matrix was designed to encompass all disciplines participating in the coordination process. However, in order to simplify testing and validation of the procedure, the initial implementation focused exclusively on clashes among MEP disciplines.

This structured and sequential methodology resulted in a simplified clash matrix, a consistent georeferencing framework, and disciplined use of visibility filters and criteria definitions, effectively reducing manual alignment efforts, minimizing false positives, and shortening overall coordination cycles.

5.4. IDS applied for Model Validation

In order to verify whether the requirements defined in the Level of Information Need tables were respected by the discipline modelers, an experimental test was carried out using the IDS file. The experiment focused on the element wall concrete panels, chosen as the representative element to exemplify the application of IDS in model verification.

1. **Creation of the IDS file:** An IDS file was created using the ACCA IDS tool. The requirements were extracted directly from the Level of Information Need tables and translated into machine-readable rules. For the wall concrete panel elements in the architectural model, the minimum alphanumeric information requirements were defined to support the quantity take-off process (e.g., Length, Width, and Gross Side Area) as well as to facilitate element identification (e.g., Name and Predefined Type attributes) (Figure 58). In addition, material properties and the corresponding classification system codes were also extracted.

2. **IDS definition:** the creation of the IDS file followed a structured workflow. The first step was to complete the general data fields, including the title, purpose, milestone, and description of the file. In the specification section, control criteria were set to define which information must be contained in the IFC file for validation. It was also necessary to specify the IFC version to be checked, which in this case was IFC 4.0. The next step involved applying filters to the desired entities and assigning the requirements to be verified. Once these parameters were defined, the software generated two outputs: a PDF report summarizing the specified requirements and an XML file to execute the IDS checking process.

Minimum alphanumeric information requirements		
IFC class		*IfcWall*
Attributes		
Name		*X*
Predefined Type		*X*
Property sets		
IsExternal	*Pset_WallCommon*	*X*
Length	*Qto_WallBaseQuantities*	*X*
Width	*Qto_WallBaseQuantities*	*X*
GrossSideArea	*Qto_WallBaseQuantities*	*X*
Materials		
Name	*IfcMaterial*	*X*
Classification		
System	**Table**	
ABNT NBR 15965-4:2021	*Table 2 – Class 2C (Products – version 1.0)*	*2C 06 02 18 00 00 00*

Figure 58 – Level of Information Need table for concrete panels in Architectural models

3. **Application of the IDS file to the BIM model:** Once defined, the IDS file was applied to the BIM model containing wall concrete panel objects. The ACCA IDS tool compared the requirements set in the IDS with the actual data contained in the model, automatically checking whether each wall panel has the necessary information (Figure 59).

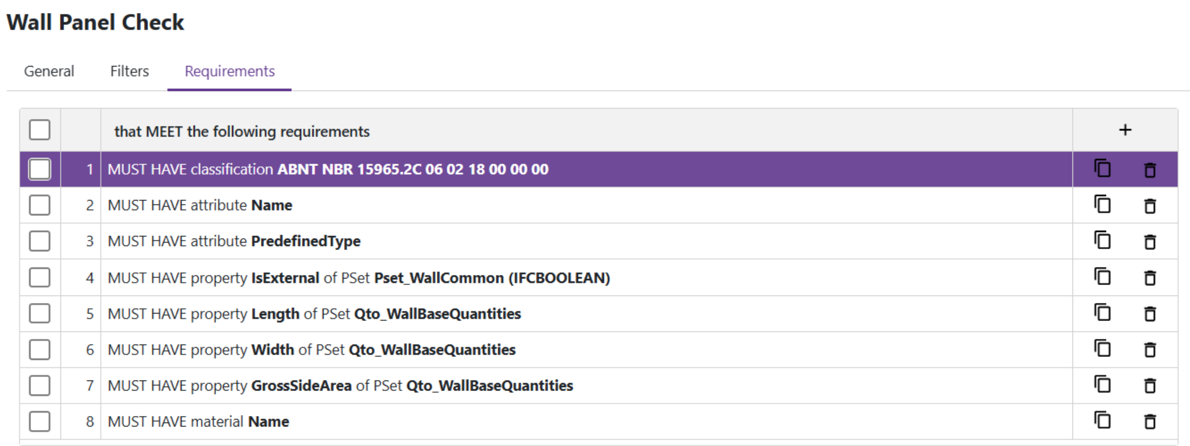


Figure 59 – ACCA IDS editor tool

4. **Visualization and analysis of results:** The verification results were also displayed within the ACCA IDS environment. The tool provided a visualization of compliant elements as well as those where information was missing or inconsistent. This made it possible to identify gaps between the information required in the Level of Information Need tables and the data actually provided by the modelers (Figure 60).

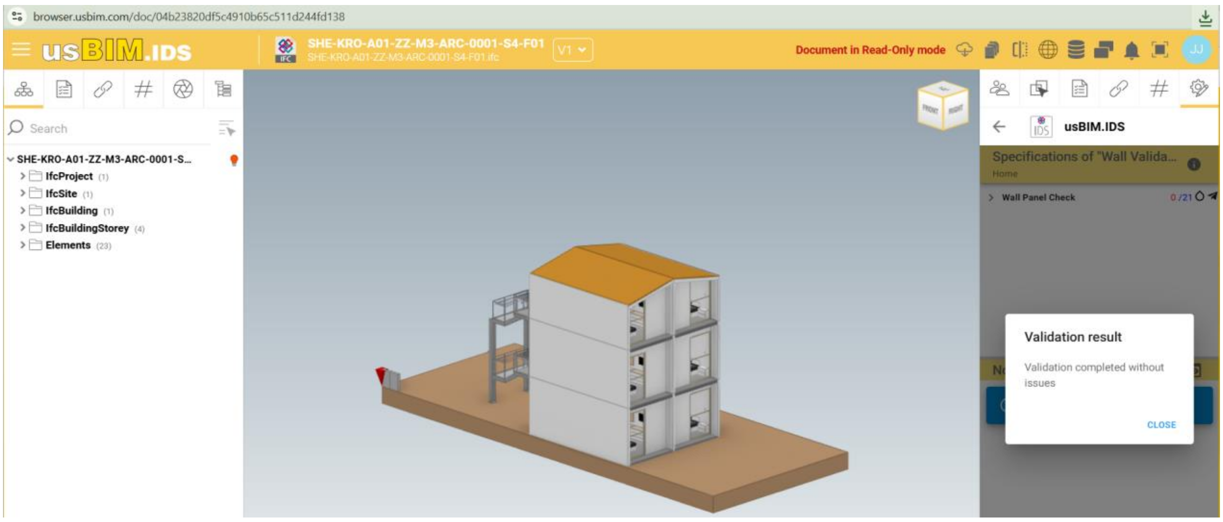


Figure 60 – ACCA IDS editor for validation

The experiment demonstrated the potential use of the IDS files as a practical instrument for information model verification between the task team and the model quality control coordination. By creating a direct connection between information requirements and BIM model content, IDS facilitates the control of informational specifications.

5.5. Quantity Take-off Process

To ensure an organized and consistent quantity take-off (QTO) process, it is essential to adopt a classification system for model elements. Such a system minimizes confusion and misinterpretation when exchanging information among different disciplines, including architects, engineers, contractors, and facility managers. Beyond supporting interoperability, the adoption of a classification framework enables the standardization of information requirements, ensuring that data can be effectively used throughout the entire project lifecycle, from the early design stages to post-construction activities, such as facility management and maintenance. By systematically identifying products and construction elements, classification enhances traceability and reliability in information use.

In this pilot project, the Brazilian classification system defined by ABNT NBR 15965 was applied. Furthermore, the definition of Level of Information Need specification tables, together with IDS verification, ensures a consistent and verifiable process. This structured approach facilitates the tracking of all construction elements within the project and strengthens the integration of BIM data across different phases and stakeholders.

To demonstrate the application of the classification system and to simulate an organized procedure for quantity take-off, a template table was developed for the concrete panel walls. It is important to emphasize that ABNT NBR 15965 provides a comprehensive framework capable of classifying not only construction elements but also all the materials and components that constitute them. For example, if the modelled element were a door, the ABNT classification system would allow the identification of all associated components, such as hinges, handles, screws, paints, the door leaf, and the frame materials. In order to simplify the process for this pilot study, Table 2 – Class 2C (Products – version 1.0) was primarily adopted (ABNT, 2022). This classification groups products in broader categories, such as general interior products, rather than distinguishing every individual component separately. This approach strikes a balance between classification detail and practicality, making the QTO process more streamlined and manageable.

The table begins with the panel ID, which assigns a unique code to each panel in the project, serving as a consistent identifier. This is followed by a 2D plan preview, allowing users to visually locate and verify which wall in the project is constructed with prefabricated concrete. Next, the table presents the classification system code for concrete walls, followed by the corresponding construction material specifications. Subsequent entries provide the quantitative data extracted from each wall, which is essential for the two main processes carried out by the project department: the Acquisition Project and the Executive Project. Finally, the last row of the table consolidates the total quantities required, including units, length, height, area, and volume. This structured organization enhances clarity, traceability, and direct applicability of the information. An example of this workflow is illustrated in the image below (Figure 61).

Concrete_Panels_Quantity_TakeOff								
ABNT NBR 15965 Classification	Painel ID	2D Rrepresentation	Material	thickness	Unit	Length	Area	Volume
2C 06 02 18 00 00 00	P-01		Concrete					
2C 06 02 18 00 00 00	P-02		Concrete					
2C 06 02 18 00 00 00	P-03		Concrete					
2C 06 02 18 00 00 00	P-XX		Concrete					
TOTAL								

Figure 61 – Precast Panel Quantity Take-off template table

By integrating a classification system, Level of Information Need tables, and IDS files, the QTO process was significantly enhanced, resulting in standardized tables that ensure reliable outputs and promote consistency across all disciplines. These standardized tables provide direct support for the planning department, first in preparing budgets for commercial proposals and later in guiding the fabrication of the concrete panels.

5.6. Modelling Challenges

The first challenge was related to the limitations of the parametric wall object, which were expected, since this was an experimental element. The parametric panel wall that was developed only supported regular shapes, specifically rectangular solids. However, in this project some panels had trapezoidal geometries to follow the slope of the roof. For these cases, native concrete walls from the BIM platform had to be used instead.

During the executive design workflow, georeferencing and model alignment posed significant difficulties, particularly when integrating models from different platforms, such as ArchiCAD (architectural model) and Revit (MEP model). Although both platforms provide georeferencing capabilities, their procedures differ, often leading to misalignments and additional coordination work. ArchiCAD uses an internal project origin and allows the definition of both a project origin and a survey point. It can also assign real-world coordinates (latitude/longitude or UTM), though its modelling environment prioritizes relative distances to avoid numerical instability. Revit, on the other hand, distinguishes between the Project Base Point (a local reference for modelling) and the Survey Point (linked to real-world coordinates). Aligning models with real coordinates in Revit requires configuring shared coordinates through the Survey Point. The main challenge arises from the fact that Revit separates local and global coordinates, while ArchiCAD integrates them simultaneously. As a result, exchanging IFC files frequently generates displacements, rotation errors, and the need for manual realignment.

Another key issue concerned clash detection and prioritization. Establishing which interferences should be checked and defining a clear clash matrix proved essential. Without prioritization, clash reports quickly become overloaded and inefficient. It was also important to clarify that physical contact between elements does not always indicate a clash, for example, hydraulic pipes embedded within walls. To avoid such false positives, building materials can be set to participate or not in collision detection, enabling selective filtering of elements in the process.

The use of IDS files with ACCA software tools was particularly beneficial. The interface is intuitive and allows the insertion of attributes, properties, materials, and other required information to verify whether the IFC model was correctly exported. Both creating an IDS and applying it to an IFC file can be performed within the same platform, streamlining the workflow. Furthermore, after analysing the IFC file, the tool automatically generates a report identifying missing information, which can be easily addressed.

For the classification system, implementing the ABNT NBR 15965 standard was essential to ensure consistency. However, it required reconfiguring object properties and training the team in standardized categorization. The most labour-intensive task was inputting the classification system into the BIM platform and assigning it to each element in the object library. Once this initial work was completed, the system proved highly useful for element identification, traceability, and quantity take-off.

Those challenges highlight the importance of process planning and training so that knowledge and procedures become consolidated as part of the team’s workflow. Standardization of processes and models, as well as interoperability between different BIM platforms, requires deliberate technical capacity building and continuous improvement. At the same time, they demonstrate the practical value of the methodological framework proposed in this dissertation for guiding future real projects.

6. CONCLUSIONS

The BIM-based framework developed in this work aimed to encourage and support medium-sized companies in the prefabricated construction industry to analyse their workflows and seek standardized procedures tailored to their needs for more efficient and consistent processes. The primary goal was to enhance design and planning practices while improving project management efficiency, following ISO 19650 guidance and recommendations. This was achieved after identifying gaps in communication and information exchange within the company's current workflow. The framework, comprising a redesigned process map, a prototype parametric wall object, a BIM Execution Plan, Exchange Information Requirements, and model validation procedures, was tested through a pilot project, demonstrating its practical applicability.

The study confirmed that BIM methodology can catalyse efficiency, coordination, and decision-making in prefabricated construction. At the same time, the pilot project revealed technical and organizational challenges that must be addressed for successful adoption. For instance, the parametric wall object supported only rectangular geometries, limiting its use for unconventional shapes such as trapezoidal panels. Nevertheless, it proved effective for conventional designs, increasing productivity, supporting early dimensioning of elements, and improving budget accuracy. Another major difficulty was the integration of the architectural and MEP models across different BIM platforms. Persistent georeferencing and alignment inconsistencies often generated displacements during IFC exchanges.

Clash detection was also found to require careful planning. Without a well-defined clash matrix and prioritization rules, detection reports can quickly become overloaded with false or irrelevant collisions. Adapting the clash matrix to the company's specific practices significantly improved its effectiveness. In addition, the use of Information Delivery Specifications (IDS) proved to be a powerful tool for ensuring data quality, providing validation mechanisms and automated reports of missing information. The adoption of the ABNT NBR 15965 classification system further supported process consistency and traceability, though its implementation demanded significant initial effort in system configuration and team training.

These findings highlight that the effectiveness of BIM does not depend only on the efficiency of technical tools, but also on process planning, standardization, and continuous capacity building within project teams. Training and organizational engagement are essential for consolidating new practices, while interoperability and structured information exchange procedures are fundamental to reducing errors and inefficiencies. In summary, this study demonstrated that a structured BIM-based framework can enhance design, planning, and project management in prefabrication by addressing interoperability challenges, strengthening team knowledge, and fostering a digital organizational culture. The lessons learned from the pilot project reinforce the importance of iterative and collaborative implementation, along with gradual refinement of methods.

For future work, the validation of the framework should be extended to different project types and company contexts. Further research should also explore advanced integration with automation, such as quantity take-off and cost estimation procedures, the refinement of parametric wall objects for greater design flexibility, and the long-term impacts of BIM adoption on cost, productivity, and efficiency. By building on these foundations, the prefabrication sector can achieve the full potential of BIM as a driver of innovation and efficiency in construction.

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LIST OF ACRONYMS AND ABBREVIATIONS

ABNT	Brazilian Association of Technical Standards
AEC	Architecture, Engineering and Construction
BCF	BIM Collaboration Format
BEP	BIM Execution Plan
BIM	Building Information Modelling
bSDD	buildingSMART Data Dictionary
EIR	Exchange Information Requirements
IDS	Information Delivery Specification
IFC	Industry Foundation Classes
ISO	International Organization for Standardization
LOIN	Level of Information Need
MEP	Mechanical Electrical and Plumbing
OIR	Organizational Information Requirements
PIR	Project Information Requirements
SME	Small and Medium-sized Enterprises

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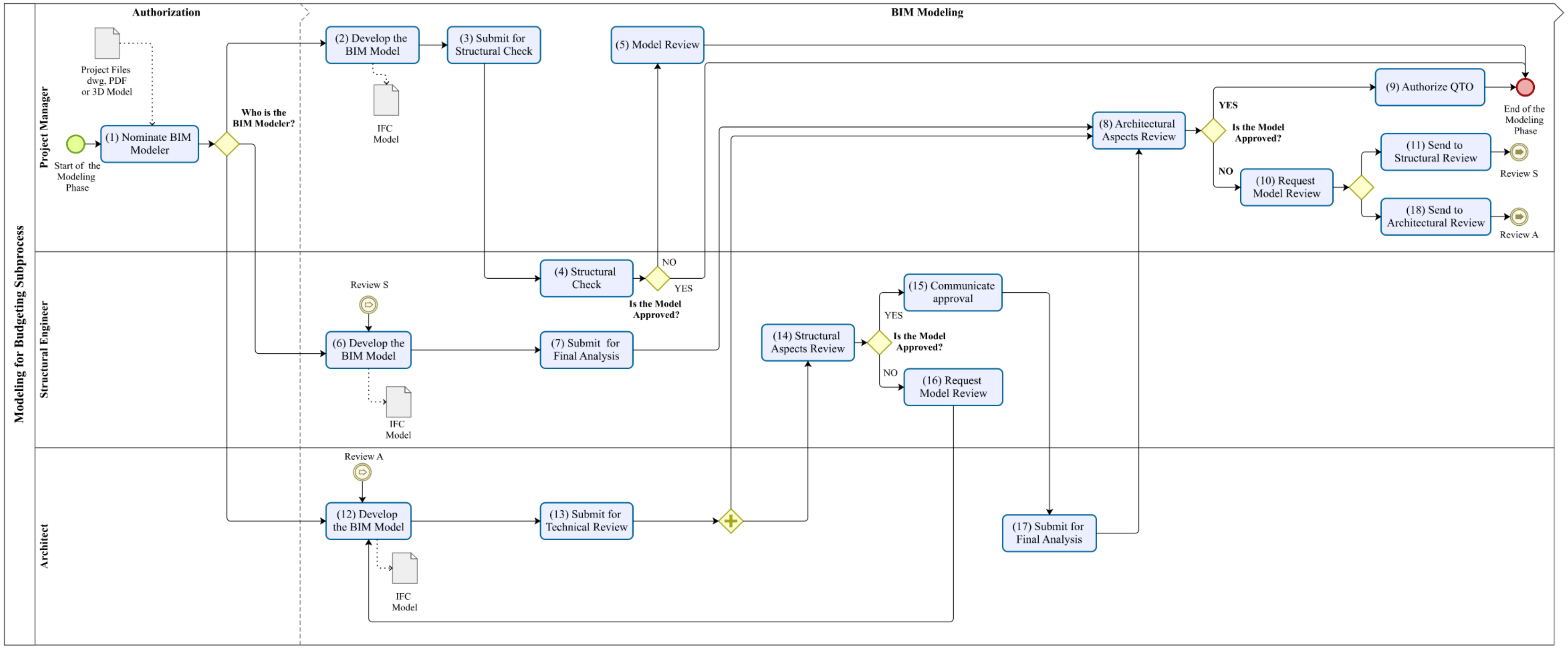
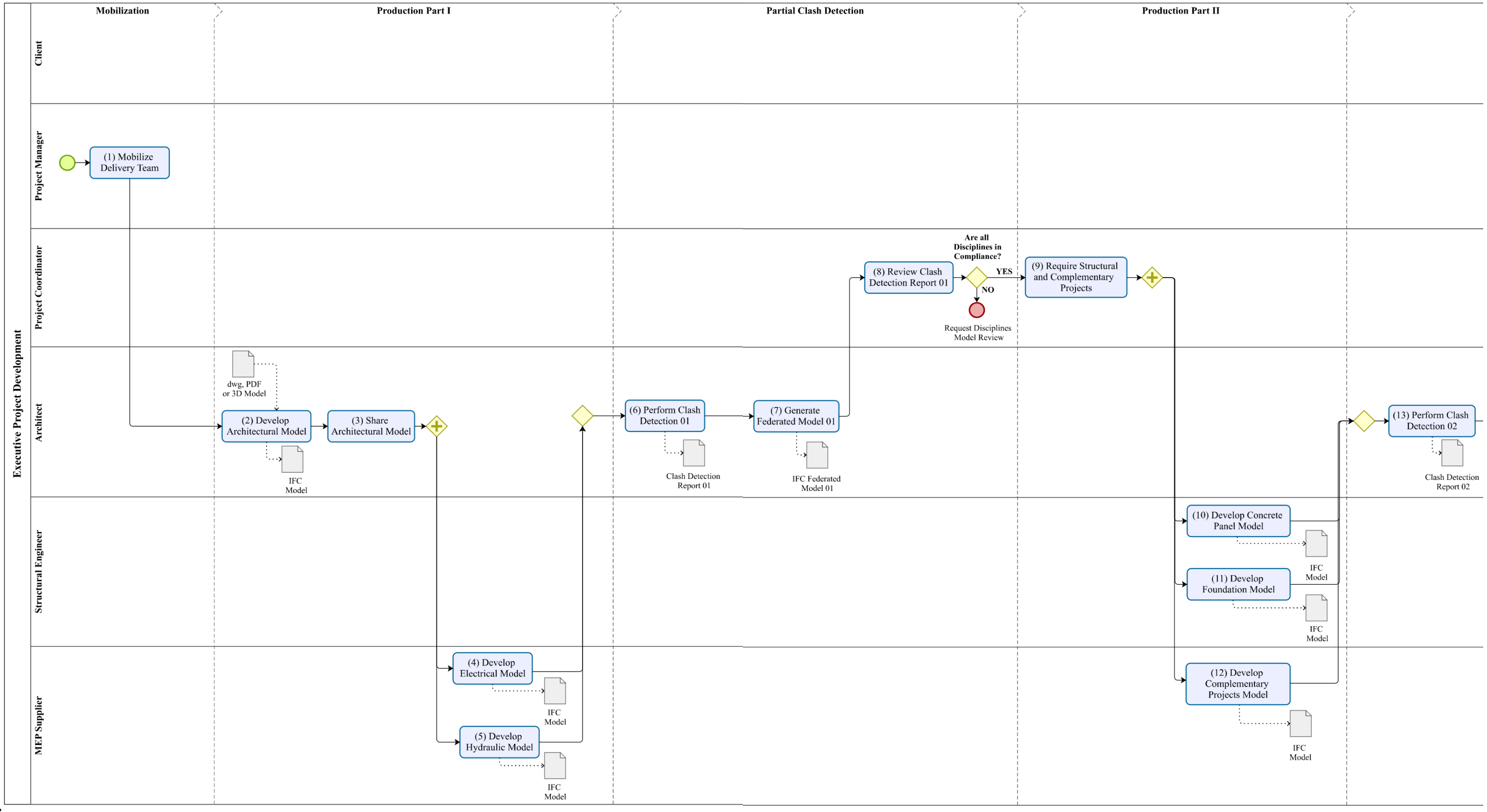
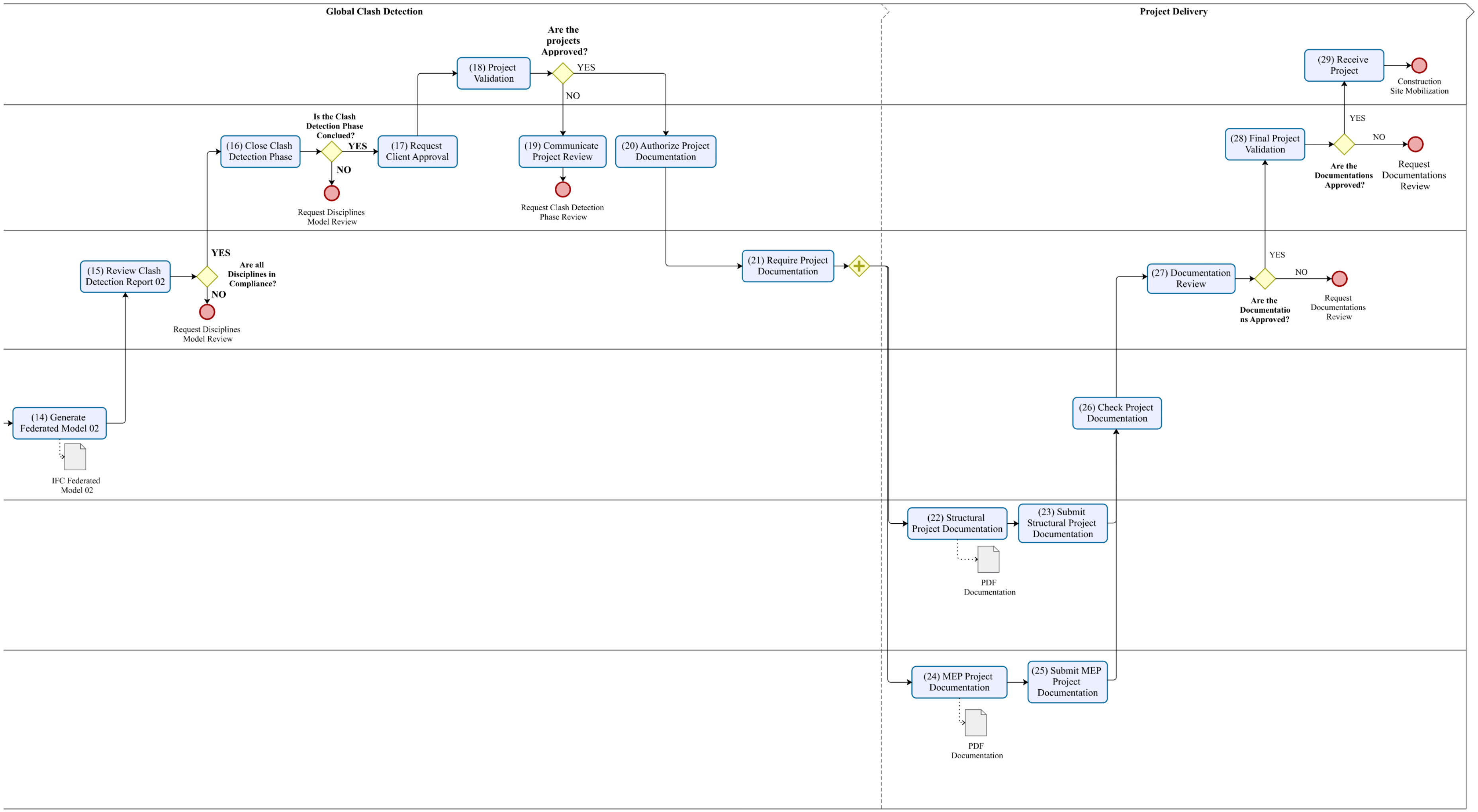
APPENDICES

APPENDIX 1: AS IS MODELLING FOR BUDGETING SUBPROCESS



APPENDIX 2: AS IS EXECUTIVE PROJECT DEVELOPMENT SUBPROCESS




Global Clash Detection
Project Delivery
Are the projects Approved?
YES
NO
(18) Project Validation
(29) Receive Project
Construction Site Mobilization
Is the Clash Detection Phase Conclued?
YES
NO
(16) Close Clash Detection Phase
(17) Request Client Approval
(19) Communicate Project Review
(20) Authorize Project Documentation
(28) Final Project Validation
Are the Documentations Approved?
Request Documentations Review
Request Disciplines Model Review
Request Clash Detection Phase Review
(15) Review Clash Detection Report 02
Are all Disciplines in Compliance?
(21) Require Project Documentation
(27) Documentation Review
Are the Documentations Approved?
Request Documentations Review
(14) Generate Federated Model 02
IFC Federated Model 02
(26) Check Project Documentation
(22) Structural Project Documentation
(23) Submit Structural Project Documentation
PDF Documentation
(24) MEP Project Documentation
(25) Submit MEP Project Documentation
PDF Documentation

APPENDIX 3: MATURITY LEVEL MATRIX

BIM CAPABILITY SETS

TECHNOLOGY based on Capability Set v5

Key Maturity Areas at Granularity level 1	a INITIAL (score 0)	b DEFINED (max score 10)	c MANAGED (max score 20)	d INTEGRATED (max score 30)	e OPTIMIZED (max score 40)
Software: applications, deliverables and data	Usage of software applications is unmonitored and unregulated. 3D Models are relied on to mainly generate accurate 2D representations/deliverables. Data usage, storage and exchanges are not defined within organisations or project teams. Exchanges suffer from a severe lack of interoperability.	Software usage/introduction is unified within an organisation or project teams (multiple organisations). 3D Models are relied upon to generate 2D as well as 3D deliverables. Data usage, storage and exchange are well defined within organisations and project teams. Interoperable data exchanges are defined and prioritised.	Software selection and usage is controlled and managed according to defined deliverables. Models are the basis for 3D views, 2D representations, quantification, specification and analytical studies. Data usage, storage and exchanges are monitored and controlled. Data flow is documented and well-managed. Interoperable data exchanges are mandated and closely monitored.	Software selection and deployment follows strategic objectives, not just operational requirements. Modelling deliverables are well synchronised across projects and tightly integrated with business processes. Interoperable data usage, storage and exchange are regulated and performed as part of an overall organisational or project-team strategy.	Selection/use of software tools is continuously revisited to enhance productivity and align with strategic objectives. Modelling deliverables are cyclically being revised/optimised to benefit from new software functionalities and available extensions. All matters related to interoperable data usage storage and exchange are documented, controlled, reflected upon and proactively enhanced.
	score	score	score	score	score
Hardware: equipment, deliverables and location/mobility	BIM equipment is inadequate; specifications are too low or inconsistent across the organisation. Equipment replacement or upgrades are treated as cost items and performed only when unavoidable.	Equipment specifications – suitable for the delivery of BIM products and services - are defined, budgeted-for and standardised across the organisation. Hardware replacements and upgrades are well-defined cost items.	A strategy is in place to transparently document, manage and maintain BIM equipment. Investment in hardware is well-targeted to enhance staff mobility (where needed) and extend BIM productivity.	Equipment deployments are treated as BIM enablers. Investment in equipment is tightly integrated with financial plans, business strategies and performance objectives.	Existing equipment and innovative solutions are continuously tested, upgraded and deployed. BIM hardware become part of organisation's or project team's competitive advantage.
	score	score	score	score	score
Network: solutions, deliverables and security/ access control	Network solutions are non-existent or ad-hoc. Individuals, organisations (single location/dispersed) and project teams use whatever tools found to communicate and share data. Stakeholders lack the network infrastructure necessary to harvest, store and share knowledge.	Network solutions for sharing information and controlling access are identified within and between organisations. At project level, stakeholders identify their requirements for sharing data/information. Dispersed organisations and project teams are connected through relatively low-bandwidth connections.	Network solutions for harvesting, storing and sharing knowledge within and between organisations are well managed through common platforms (ex: intranets or extranets). Content and asset management tools are deployed to regulate structured and unstructured data shared across high-bandwidth connections.	Network solutions enable multiple facets of the BIM process to be integrated through seamless real-time sharing of data, information and knowledge. Solutions include project-specific networks/portals which enable data-intensive interchange (interoperable exchange) between stakeholders.	Network solutions are continuously assessed and replaced by the latest tested innovations. Networks facilitate knowledge acquisition, storing and sharing between all stakeholders. Optimisation of integrated data, process and communication channels is relentless.
	score	score	score	score	score

LEGEND

CURRENT

DESIRED

PROCESS based on Capability Set v5.0

Key Maturity Areas at Granularity level 1	a INITIAL (score 0)	b DEFINED (max score 10)	c MANAGED (max score 20)	d INTEGRATED (max score 30)	e OPTIMIZED (max score 40)
Resources: Physical and knowledge infrastructure	The work environment is either not recognised as a factor in staff satisfaction or may not be conducive to productivity. Knowledge is not recognised as an asset; BIM knowledge is typically shared informally between staff (through tips, techniques and lessons learned).	The work environment and workplace tools are identified as factors affecting motivation and productivity. Similarly, knowledge is recognised as an asset; shared knowledge is harvested, documented and thus transferred from tacit to explicit.	The work environment is controlled, modified and its criteria managed to enhance staff motivation, satisfaction and productivity. Also, documented knowledge is adequately stored.	Environmental factors are integrated into performance strategies. Knowledge is integrated into organisational systems; stored knowledge is made accessible and easily retrievable.	Physical workplace factors are reviewed constantly to insure staff satisfaction and an environment conducive to productivity. Similarly, knowledge structures responsible for acquisition, representation and dissemination are systemically reviewed and enhanced.
	score	score	score	score	score
Activities & Workflows: Knowledge, skills, experience, roles and relevant dynamics	There is an absence of defined processes; roles are ambiguous and team structures/dynamics are inconsistent. Performance is unpredictable and productivity depends on individual heroics. A mentality of 'working 'around the system' flourishes.	BIM roles are informally defined and teams are formed accordingly. Each BIM project is planned independently. BIM competency is identified and targeted; BIM heroism fades as competency increases but productivity is still unpredictable.	Cooperation within organisations increases as tools for cross-project communication are made available. Flow of information steadies; BIM roles are visible and targets are achieved more consistently.	BIM roles and competency targets are imbedded within the organisation. Traditional teams are replaced by BIM-oriented ones as new processes become part of organisation/ project team's culture. Productivity is now consistent and predictable.	BIM competency targets are continuously upgraded to match technological advances and align with organisational objectives. Human resource practices are proactively reviewed to insure intellectual capital matches process needs.
	score	score	score	score	score
Products & Services: Specification, differentiation and R&D	3D models deliverables (a BIM product) suffer from too high, too low or inconsistent levels of detail.	A "statement defining the object breakdown of the 3D model" is available.	Adoption of product/ service specifications similar to Model Progression Specifications, BIPS 'information levels' or similar.	Products and services are specified and differentiated according to Model Progression Specifications or similar.	BIM products and services are constantly evaluated; feedback loops promote continuous improvement.
	score	score	score	score	score
Leadership & Management: Organisational, strategic, managerial and communicative attributes; innovation and renewal	Senior leaders/ managers have varied visions about BIM. BIM implementation (according to BIM Stage requirements) is conducted without a guiding strategy. At this maturity level, BIM is treated as a technology stream; innovation is not recognised as an independent value and business opportunities arising from BIM are not acknowledged.	Senior leaders/managers adopt a common vision about BIM. BIM implementation strategy lacks actionable details. BIM is treated as a process-changing, technology stream. Product and process innovations are recognised; business opportunities arising from BIM are identified but not exploited.	The vision to implement BIM is communicated and understood by most staff. BIM implementation strategy is coupled with detailed action plans and a monitoring regime. BIM is acknowledged as a series of technology, process and policy changes which need to be managed without hampering innovation. Business opportunities arising from BIM are acknowledged and used in marketing efforts.	The vision is shared by staff across the organisation and/or project partners. BIM implementation, its requirements and process/ product innovation are integrated into organisational, strategic, managerial and communicative channels. Business opportunities arising from BIM are part of team, organisation or project-team's competitive advantage and are used to attract and keep clients.	Stakeholders have internalised the BIM vision and are actively achieving it. BIM implementation strategy and its effects on organisational models are continuously revisited and realigned with other strategies. If alterations are needed, they are proactively implemented. Innovative product/ process solutions and business opportunities are sought-after and followed through relentlessly.
	score	score	score	score	score

LEGEND

CURRENT

DESIRED

	Key Maturity Areas at Granularity level 1	a INITIAL (score 0)	b DEFINED (max score 10)	c MANAGED (max score 20)	d INTEGRATED (max score 30)	e OPTIMIZED (max score 40)
POLICY based on Capability Set v5.0	**Preparatory:** research, educational / training programmes and deliverables	Very little or no training available to BIM staff. Educational/ training mediums are not suitable to achieve the results sought.	Training requirements are defined and are typically provided only when needed. Training mediums are varied allowing flexibility in content delivery.	Training requirements are managed to adhere to pre-set broad competency and performance objectives. Training mediums are tailored to suit trainees and to reach learning objectives in a cost-effective manner.	Training is integrated into organisational strategies and performance targets. Training is typically based on staff roles and respective competency objectives. Training mediums are incorporated into knowledge and communication channels.	Training is continuously evaluated and improved upon. Training availability and delivery methods are tailored to allow multi-modal continuous learning.
		score	score	score	score	score
	Regulatory: codes, regulations, standards, classifications, guidelines and benchmarks	There are no BIM guidelines, documentation protocols or modelling standards. There is an absence of documentation and modelling standards. There is informal or no quality control plans; neither for 3D models nor for documentation. There are no performance benchmarks for processes, products or services.	Basic BIM guidelines are available (ex: training manual and BIM delivery standards). Modelling and documentation standards are well defined according to market-accepted standards. Quality targets and performance benchmarks are set.	Detailed BIM guidelines are available (training, standards, workflow, exceptions...). Modelling, representation, quantification, specifications and analytical properties of 3D models are managed through detailed modelling standards and quality plans. Performance against benchmarks is tightly monitored and controlled.	BIM guidelines are integrated into overall policies and business strategies. BIM standards and performance benchmarks are incorporated into quality management and performance improvement systems.	BIM guidelines are continuously and proactively refined to reflect lessons learned and industry best practices. Quality improvement and adherence to regulations and codes are continuously aligned and refined. Benchmarks are repetitively revisited to insure highest possible quality in processes, products and services.
		score	score	score	score	score
	Contractual: responsibilities, rewards and risk allocations	Dependence on pre-BIM contractual arrangements. Risks related to model-based collaboration are not recognised or are ignored.	BIM requirements are recognised. "Statements defining the responsibility of each stakeholder regarding information management" are now available.	There is a mechanism to manage shared BIM intellectual property, confidentiality, liability and a system for BIM conflict resolution.	Organisation are aligned through trust and mutual dependency beyond contractual barriers.	Responsibilities, risks and rewards are continuously revisited and realigned to effort. Contractual models are modified to achieve best practices and highest value for all stakeholders.
		score	score	score	score	score
STAGE 1	**Object-based Modelling**: single-disciplinary use within a Project Lifecycle phase	Implementation of an object-based tool. No process or policy changes identified to accompany this implementation.	Pilot projects are concluded. BIM process and policy requirements are identified. Implementation strategy and detailed plans are prepared.	BIM processes and policies are instigated, standardised and controlled.	BIM technologies, processes and policies are integrated into organisational strategies and aligned with business objectives.	BIM technologies, processes and policies are continuously revisited to benefit from innovation and achieve higher performance targets.
		score	score	score	score	score

LEGEND

CURRENT

DESIRED

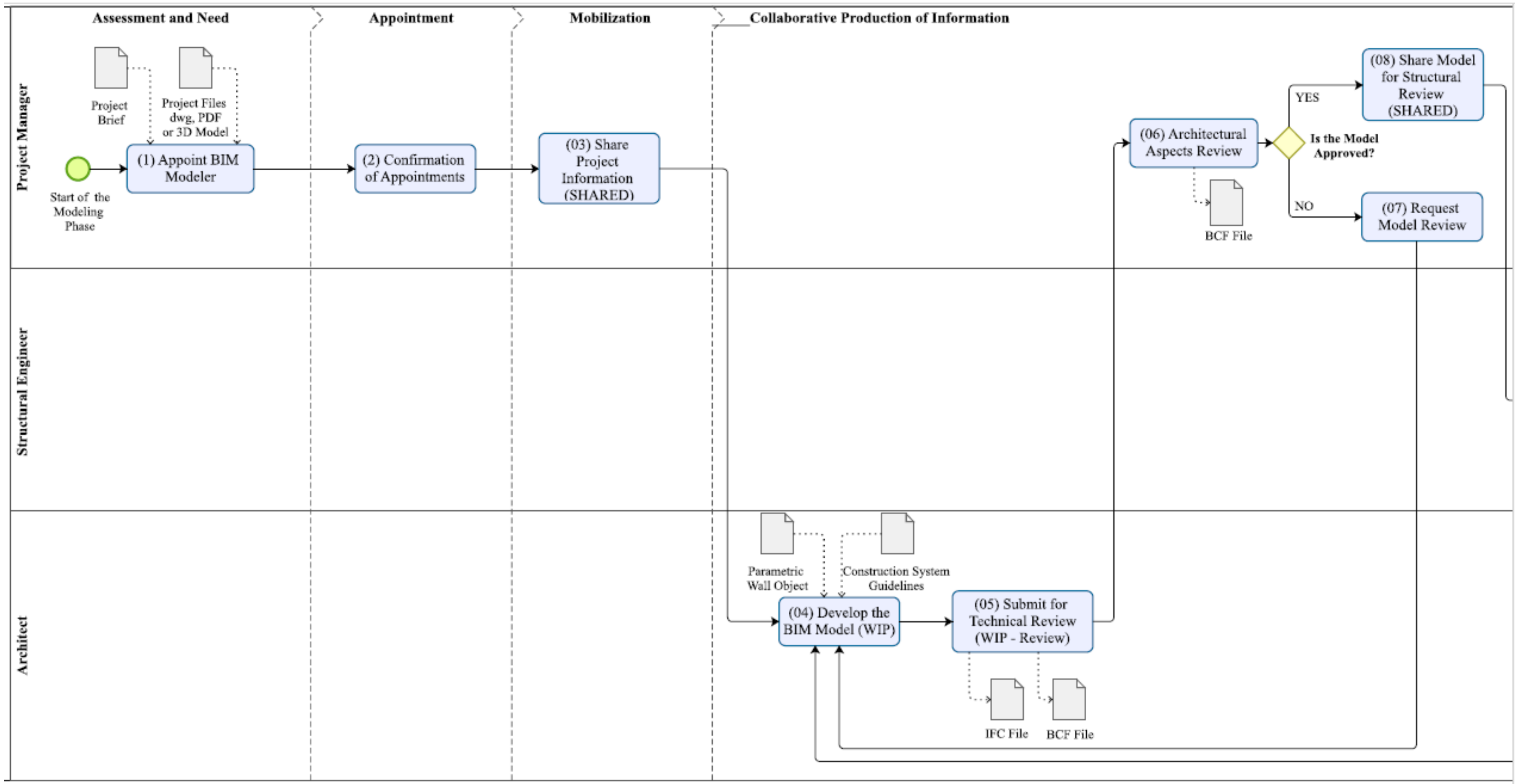
		Key Maturity Areas at Granularity level 1	a INITIAL (score 0)	b DEFINED (max score 10)	c MANAGED (max score 20)	d INTEGRATED (max score 30)	e OPTIMIZED (max score 40)
	STAGE 2	**Modelling-based Collaboration**: multi-disciplinary, fast-tracked interchange of models	Ad-hoc BIM collaboration: in-house collaboration capabilities incompatible with project partners. Trust and respect between project participants may be lacking.	Single-thread, well-defined yet reactive BIM collaboration. There are identifiable signs of mutual trust and respect among project participants.	Multi-thread proactive collaboration: protocols are well documented and managed. There are mutual trust, respect and sharing of risks and rewards among project participants.	Multi-thread collaboration includes downstream players. This is characterised by the involvement of key participants during projects' early lifecycle phases.	Multi-thread team included all key players in an environment characterised by goodwill, trust and respect.
			score	score	score	score	score
	STAGE 3	**Network-based Integration**: concurrent interdisciplinary interchange of nD models across Project Lifecycle Phases	Integrated models are generated by a limited set of project stakeholders - possibly behind corporate firewalls. Integration occurs with little or no pre-defined process guides, standards or interchange protocols. There is no formal resolution of stakeholders' roles and responsibilities.	Integrated models are generated by a large subset of project stakeholders. Integration follows predefined process guides, standards and interchange protocols. Responsibilities are distributed and risks are mitigated through contractual means.	Integrated models (or parts of) are generated and managed by most project stakeholders. Responsibilities are clear within temporary project alliances or longer-term partnerships. Risks and rewards are actively managed and distributed.	Integrated models are generated and managed by all key project stakeholders. Network-based integration is the norm and focus is no longer on *how* to integrate models/workflows but on proactively detecting and resolving technology, process and policy misalignments.	Integration of models and workflows are continuously revisited and optimised. New efficiencies, deliverables and alignments are actively pursued by a tightly-knit interdisciplinary project team. Integrated models are contributed to by many stakeholders along the construction supply chain.
			score	score	score	score	score
ORG SCALE	MICRO	**Organisations**: dynamics and BIM deliverables	BIM leadership is non-existent; implementation depends on technology champions.	BIM leadership is formalised; different roles within the implementation process are defined.	Pre-defined BIM roles complement each other in managing the implementation process.	BIM roles are integrated into organisation's leadership structures.	BIM leadership continuously mutates to allow for new technologies, processes and deliverables.
			score	score	score	score	score
	MESO	**Project Teams**: (multiple organisations): inter-organisational dynamics and BIM deliverables	Each project is run independently. There is no agreement between stakeholders to collaborate beyond their current common project.	Stakeholders think beyond a single project. Collaboration protocols between project stakeholders are defined and documented.	Collaboration between multiple organisations over several projects is managed through temporary alliances between stakeholders.	Collaborative projects are undertaken by inter-disciplinary organisations or multidisciplinary project teams; an alliance of many key stakeholders.	Collaborative projects are undertaken by self-optimising project teams which include most stakeholders.
			score	score	score	score	score
	MACRO	**Markets**: dynamics and BIM deliverables *(only apply this topic if assisted by a trained assessor)*	Very few supplier-generated BIM components (virtual products and materials representing physical ones). Most components are prepared by software developers and end-users.	Supplier-generated BIM components are increasingly available as manufactures/suppliers identify the business benefits.	BIM Components are available through highly accessible/searchable central repositories. Components are not interactively connected to suppliers' databases.	Access to component repositories are integrated into BIM software. Components are interactively linked to source databases (for price, availability, etc...).	Dynamic, multi-way generation and interchange of BIM components (virtual products and materials) between all project stakeholders through central or meshed repositories.
			score	score	score	score	score

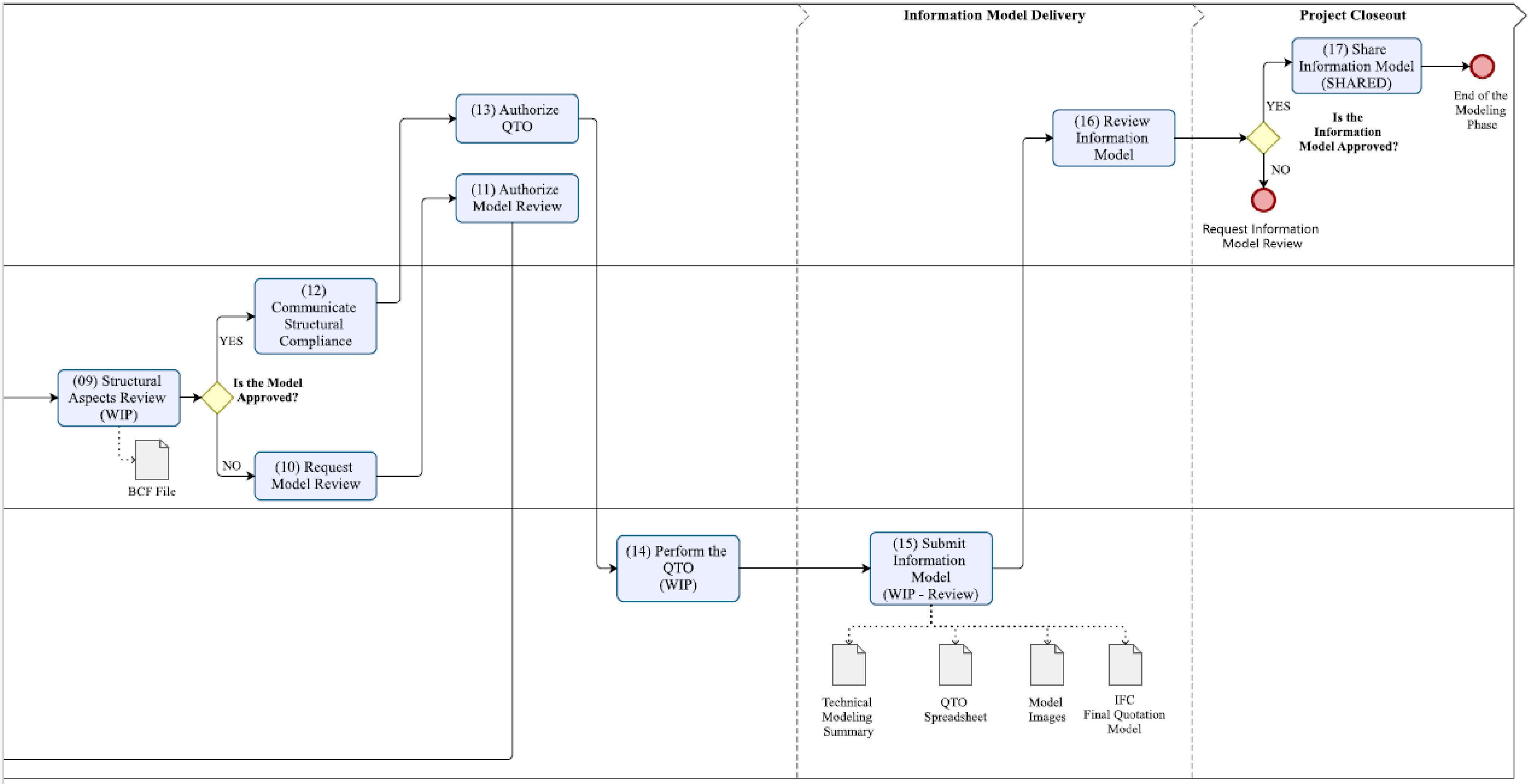
LEGEND

CURRENT

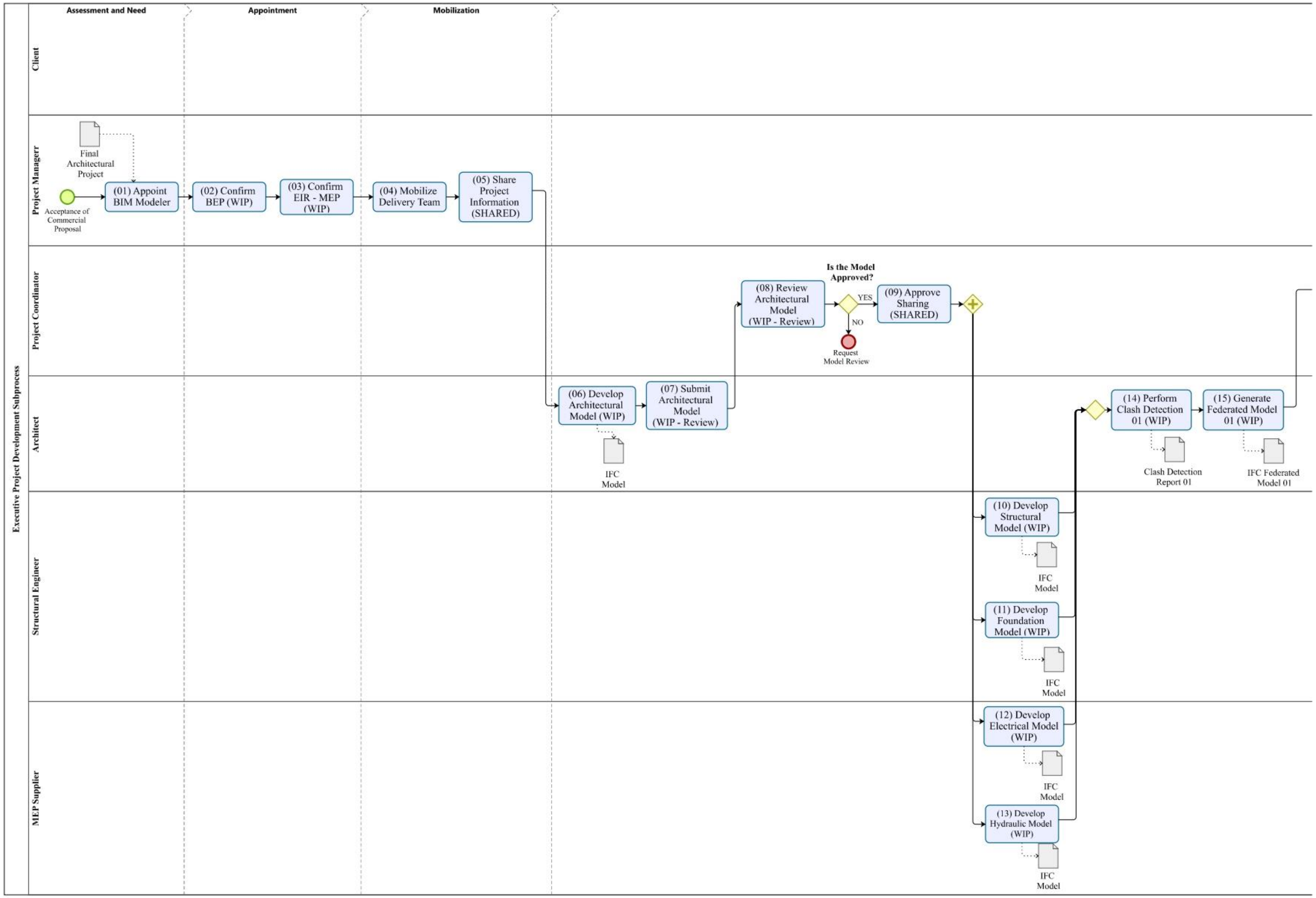
DESIRED

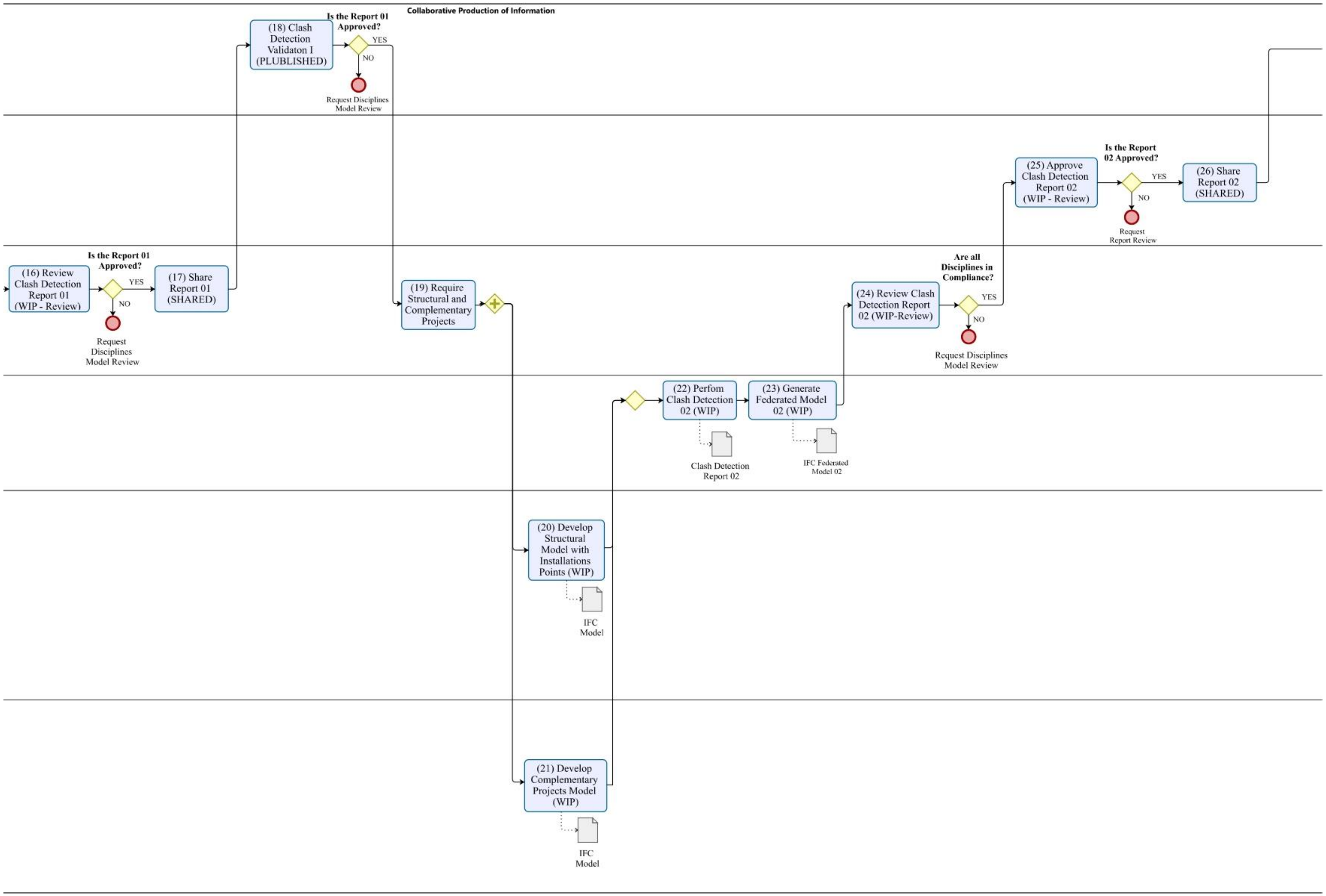
APPENDIX 4: TO BE MODELLING FOR BUDGETING SUBPROCESS

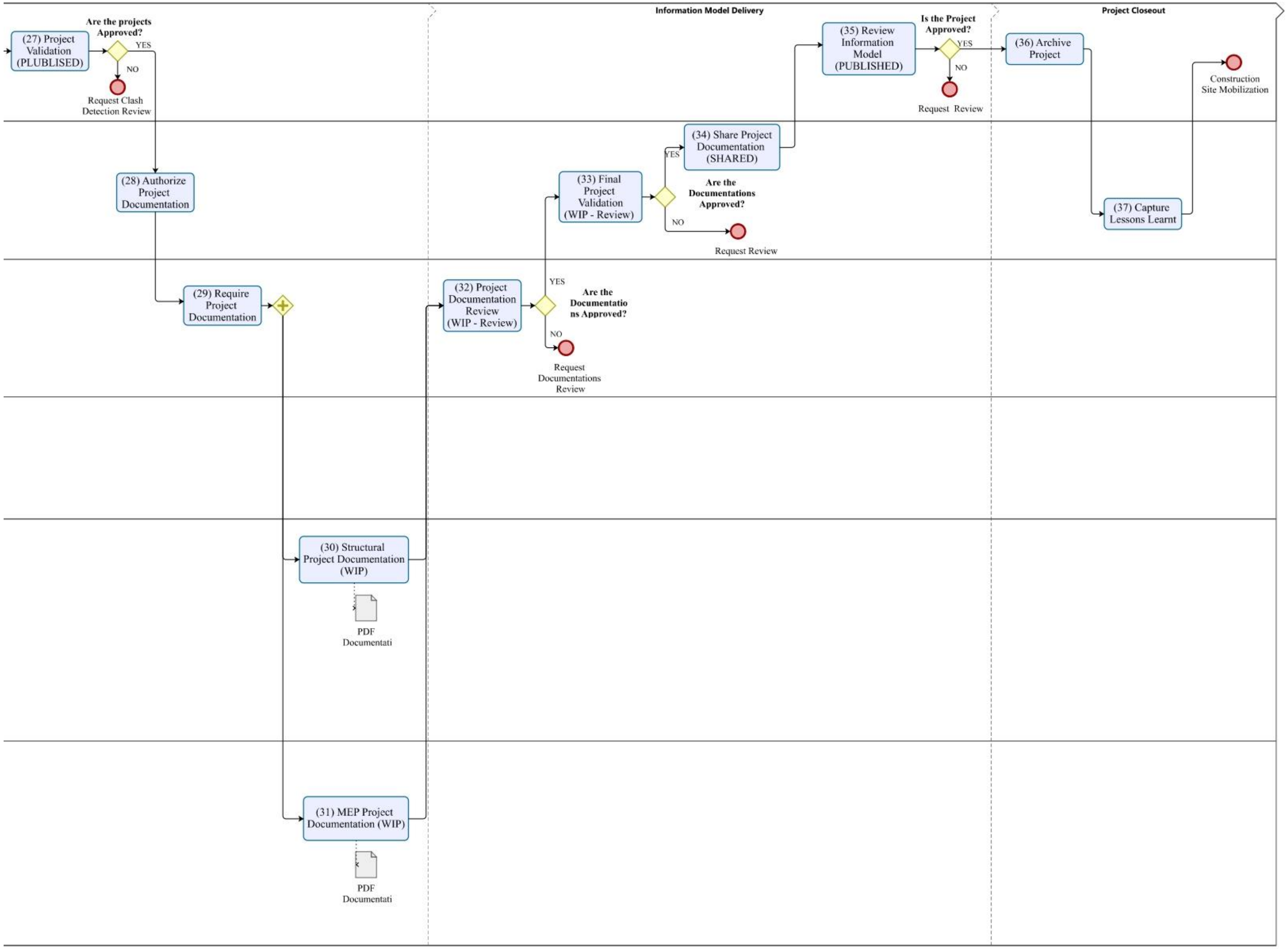



Information Model Delivery
Project Closeout
(17) Share Information Model (SHARED)
End of the Modeling Phase
YES
Is the Information Model Approved?
NO
Request Information Model Review
(16) Review Information Model
(13) Authorize QTO
(11) Authorize Model Review
(12) Communicate Structural Compliance
YES
(09) Structural Aspects Review (WIP)
Is the Model Approved?
NO
(10) Request Model Review
BCF File
(14) Perform the QTO (WIP)
(15) Submit Information Model (WIP - Review)
Technical Modeling Summary
QTO Spreadsheet
Model Images
IFC Final Quotation Model

APPENDIX 5: TO BE EXECUTIVE PROJECT DEVELOPMENT SUBPROCESS




Collaborative Production of Information
(18) Clash Detection Validaton I (PLUBLISHED)
Is the Report 01 Approved?
YES
NO
Request Disciplines Model Review
(16) Review Clash Detection Report 01 (WIP - Review)
Is the Report 01 Approved?
YES
NO
Request Disciplines Model Review
(17) Share Report 01 (SHARED)
(19) Require Structural and Complementary Projects
(20) Develop Structural Model with Installations Points (WIP)
IFC Model
(21) Develop Complementary Projects Model (WIP)
IFC Model
(22) Perfom Clash Detection 02 (WIP)
Clash Detection Report 02
(23) Generate Federated Model 02 (WIP)
IFC Federated Model 02
(24) Review Clash Detection Report 02 (WIP-Review)
Are all Disciplines in Compliance?
YES
NO
Request Disciplines Model Review
(25) Approve Clash Detection Report 02 (WIP - Review)
Is the Report 02 Approved?
YES
NO
Request Report Review
(26) Share Report 02 (SHARED)


Information Model Delivery
Project Closeout
(27) Project Validation (PLUBLISED)
Are the projects Approved?
YES
NO
Request Clash Detection Review
(28) Authorize Project Documentation
(29) Require Project Documentation
(30) Structural Project Documentation (WIP)
PDF Documentati
(31) MEP Project Documentation (WIP)
PDF Documentati
(32) Project Documentation Review (WIP - Review)
Are the Documentations Approved?
YES
NO
Request Documentations Review
(33) Final Project Validation (WIP - Review)
Are the Documentations Approved?
YES
NO
Request Review
(34) Share Project Documentation (SHARED)
(35) Review Information Model (PUBLISHED)
Is the Project Approved?
YES
NO
Request Review
(36) Archive Project
(37) Capture Lessons Learnt
Construction Site Mobilization

APPENDIX 6: BIM EXECUTION PLAN (BEP)

Project BIM Execution Plan

[Study HOUSE]

Revision [R02]

Submitted Date: [02/06/2025]

1. BIM Execution Plan Overview

This document outlines the BIM Execution Plan (BEP) for the technical design phase of the [Student Housing] project located in [Campinas, São Paulo, Brazil]. It follows the guidelines of EN ISO 19650-2:2018 and complies with applicable Brazilian regulations.

The BEP provides a structured framework for the effective implementation of Building Information Modelling (BIM) across the project. It defines the roles and responsibilities of all stakeholders, specifies the project scope, details the required information exchanges, and establishes the workflows to be followed throughout the design process.

2. Project Information

2.1 General Information

The following table defines the basic Study HOUSE project reference information.

Project Name	Study HOUSE
Client Names	BIM A+
Project Number	241
Project Code	SHE
Project Location	Av. José Próspero Jacobucci, 441-449 - Jardim Santa Genebra, Campinas - SP, 13086, Brazil
Contract Type/Delivery Method	**Redesign-Construction Scope**
Project Size	174,36 m²
Number of Floors	3
General Project Description	Student housing, one building, 6 House Studio units.
Start Date	16/06/2025 [DD/MM/YYYY]
Completion Date	09/09/2025 [DD/MM/YYYY]

2.2 Relevant Contacts

For this project, the individuals assigned to the information management function, along with their delivery team nominations and contact details, are listed in the table below.

Role	Contact Name	E-Mail	Phone
Project Manager	[P.M. Name]	pm@kronan.com.br	+55 (XX) X XXXX-XXXX
Project Coordinator	[P.C. Name]	pc@kronan.com.br	+55 (XX) X XXXX-XXXX
General Director	[G.D. Name]	gd@kronan.com.br	+55 (XX) X XXXX-XXXX

Planning Manager	[P.A. Name]	pa@kronan.com.br	+55 (XX) X XXXX-XXXX
Commercial Manager	[C.M. Name]	cm@kronan.com.br	+55 (XX) X XXXX-XXXX
Architect	[B.A Name]	ba@kronan.com.br	+55 (XX) X XXXX-XXXX
Structural Engineer	[B.S Name]	bs@kronan.com.br	+55 (XX) X XXXX-XXXX
MEP Engineer	[B.M. Name]	bm@gmail.com	+55 (XX) X XXXX-XXXX
Complementary Projects	[B.P Name	bp@gmail.com	+55 (XX) X XXXX-XXXX

2.3 Project Milestones

BIM milestones and major events that will occur during the project lifecycle.

Project Milestone	Estimated Start Date	Estimated Completion Date	Estimated Days of work	Project Stakeholders Involved
Design Phase (Architectural, Structure and MEP)	19/06/2025	03/07/2025	15	B.A. / B.S / B.M
Federated Model + Clash Detection 01	03/07/2025	10/07/2025	7	B.A. / P.M. / P.C.
Federated Model + Clash Detection 02	10/07/2025	24/07/2025	15	B.A. / B.S / B.M / P.M. / P.C.
Final Federated Model	24/07/2025	31/07/2025	7	B.A. / P.M. / P.C.
2D Documentation	31/07/2025	14/08/2025	15	B.A. / B.S / B.M

2.4 Project Goals and BIM Uses

The table below describes the Project Goals and BIM Uses throughout the Design Phase.

BIM Objective	**Description**
Design Authoring	Create and represent Architectural, Structural and MEP design.
Structural Analysis	Simulate and evaluate the building structural behaviour. Ensure compliance with safety codes and other project disciplines.
MEP Analysis	Analyse mechanical, electrical and plumbing systems. Ensure compliance with safety codes and other project disciplines.
3D Coordination	Identify, manage, and resolve conflicts or clashes between disciplines.
Design Review	Evaluate and validate the design functionality, compliance and coordination across disciplines.
Quantity Take-Off	Perform Quantity Take-Off for discipline models.

3. Roles and Responsibilities

3.1. Responsibility Matrix

According to the project goals, BIM Uses and organizational roles, the following table evidences the responsibilities of each member in the project staff.

Task/Deliverable	**Appointed Party (client)**	**Architect**	**Structural Engineer**	**MEP Engineer**	**Project Manager**	**Project Coordinator**
BIM Execution Plan (BEP)	I	C	C	C	R/A	R
Design Authoring - Architectural 2D Data input	A/R	I	I	I	I	I
Design Authoring - Architecture BIM Model	I	R	I	I	I	A
Design Authoring and Structural Analysis - Structure BIM Model	I	I	R	I	I	A
Design Authoring and MEP Analysis - MEP BIM Model	I	I	I	R	I	A
Clash Detections	I	R	C	C	A	R
Design Authoring - Documentation	I	R	R	R	C	A
3D Coordination	I	I	I	I	A	R
Design Review	I	I	I	I	A	R
Quantity Take-Off	I	R	R	R	I	A
Legend: ***Primary Responsibility*** **R = Responsible (Does the work)** **A = Accountable (Owns the outcome)** ***Not directly responsible / may support if needed*** **C = Consulted (Input required)** **I = Informed (Kept in the loop)**						

5. Process Mapping

Check APPENDIX 5: EXECUTIVE PROJECT PROCESS.

6. Information Requirements

6.1. Exchange Information Requirement (EIR)

The following table defines Project Information Requirements (PIR) and the respective Exchange Information Requirements (EIR) that represent the minimum requirements that must be incorporated into the federated model to ensure consistency, accuracy, and coordination across disciplines:

PIR Purposes	EIR	Exchange Information Requirement (EIR)
PIR01 - Regulatory and Sustainability Compliance	EIR01 - Site Context and Geolocation Data	The model must include a comprehensive representation of the terrain, capturing the property boundaries and contours (including elevation data and contour lines), existing buildings and infrastructure, utility entry points (water, sewage, electricity, telecom/data), access roads and circulation routes, vegetation and landscape features, geolocation data (true north and coordinates).
PIR03 - Integrated Design Coordination	EIR02 - Discipline Models Design	The discipline models (Architecture, Structure, MEP) must be: properly georeferenced, aligned with the Level of Information Need, be submitted in IFC open format to be validated by IDS files application and follow the naming convention.
PIR03 - Integrated Design Coordination	EIR03 - Clash Detection and Model Coordination	A federated model must be produced to coordinate disciplines. The Lead Appointed Party is responsible for: running clash detection and compiling results. The issues must be solved through collaborative meetings.
PIR01 - Regulatory and Sustainability Compliance PIR03 - Integrated Design Coordination	EIR04 - Regulatory and BIM Compliance Validation	The Lead Appointed Party must ensure that the federated model complies with regulatory codes and the Appointing Party requirements. Also, solve all the model conflicts, coordinate Delivery Milestones and Quality through BEP and EIR Acceptance Criteria.
PIR03 - Integrated Design Coordination	EIR05 - Design Documentation	Each discipline must submit: 2D drawings extracted from the discipline models (e.g., floor plans, sections, elevations), technical specifications and design reports related to each discipline.

PIR02 - Feasibility and Investment Planning	EIR06 - Quantity Take-Off from Model	The quantities should be derived directly from model geometry. The quantities must be aligned with the model's classification system following the ABNT NBR 15965. Be exported in .xlsx format for cost estimation.
PIR04 - Construction Assembly and Digital Delivery	EIR07 - Execution Support	Prepare detailed work maps and quantity maps for site use: including element breakdowns, assembly sequences and 3D view to support on-site digitals workflows (tablet-based model navigation)

5.2 Level of Information Need

The Level of Information Need (EN ISO 7817-1:2024) reference tables (APPENDIX 9) focus on the Technical Design phase for the architecture, structure, and MEP disciplines. They must be followed for exchanges of information between the Lead Appointed Party delivery team members. The appointed Parties must add relevant alphanumeric information in the tables. The IFC model must also contain the same information related to the object to extract quantities.

6. Master Information Delivery Plan (MIDP)

The following table outlines the stakeholders involved in key project phase milestones and provides general timeframes for the development of the federated model and its disciplines.

Project Stage / Milestone		**Estimated Start Date**	**Estimated Completion Date**	**Estimated Days of work**	**Project Stakeholders Involved**
Design Phase					
Architectural Model	Reconstruction of the architectural project in 2D drawings to 3D BIM model	19/06/2025	26/06/2025	7	Architect [B.A.]
Panel Structural Model	Concrete panel structural design	27/06/2025	11/07/2025	15	Structural Engineer [B.S]
Foundation Model	Foundation design	27/06/2025	11/07/2025		Structural Engineer [B.S]
MEP Model	Design of the Plumbing and	14/07/2025	28/07/2025		MEP Engineer [B.M]

	Electrical Models			15	
Additional Projects	Complementary projects such as Photovoltaic project	14/07/2025	28/07/2025		Complementary Projects [B.P]
Federated Model 01					
Federated Model	First version of the federated model for clash detection	29/07/2025	12/08/2025	7	Architect [B.A.]
Clash Detection 01	First version of the clash detection report	13/08/2025	18/08/2025	3	Architect [B.A.]
Federated Model 02					
Federated Model	Second version of the federated model for	19/08/2025	26/08/2025	7	Architect [B.A.]
Global Clash Detection	Final version of the clash detection report	27/08/2025	01/09/2025	3	Architect [B.A.]
Final Federated Mode	Final version of the federated model for	02/09/2025	09/09/2025	7	Architect [B.A.]
Documentation Phase					
Panel and Foundation documentation	Final 2D and 3D Foundation documentation				Structural Engineer [B.S]
MEP Documentation	Final 2D and 3D MEP documentation	02/09/2025	09/09/2025	15	MEP Engineer [B.M]
Additional Projects	Final 2D and 3D Additional Projects documentation	02/09/2025	09/09/2025		Complementary Projects [B.P]

7. Collaboration Procedures

7.1 Common Data Environment (CDE)

The Common Data Environment (CDE) to be used for this project is Autodoc, it must be used as a centralized digital space where the project information is stored, managed, and shared with the stakeholders.

Following the recommendations of ISO 19650, folders must be created according to theirs states of information:

Work in progress: Information being developed by the task team, only visible to the BIM discipline modeler, BIM Manager, and BIM Coordinator.

1. Shared: Information approved by the BIM Manager for sharing with other appropriate task teams and delivery teams or with the appointing party.

2. Published: Information authorized by the BIM Manager for use in more detailed design, for construction, or for asset management.

3. Archive: trail of information containers developed.

7.2 Naming convention

The file names must follow ISO 19650-2 schema, as shown below:

[Project-Originator-Volume-Level-Type-Role-Number]

For detailed information on the codes and their meanings, please refer to APPENDIX 8.

7.3 File Formats

(CDE) AUTODOC	Architectural Model	Structure Model	MEP Model	Federated Models	2D Docs	QTO
WIP	PLN	.db1	RVT	PLN	PDF	xlsx
Shared	IFC 4	IFC 4	IFC 4	IFC 4	DWG PDF	xlsx
Published	IFC 4	IFC 4	IFC 4	IFC 4	DWG PDF	xlsx PDF

7.4 Meetings Procedures

Meeting Type	Project Stage	Frequency	Participants
BIM requirements design kick-off	Planning	Once	Client / Planning Manager [P.A.] / Project Manager [P.M.] / Project Coordinator [P.C.] / Architect [B.A.]
BIM Execution Plan Review - Design	Planning	Once	Client / Planning Manager [P.A.] / Project Manager [P.M.] / Project Coordinator [P.C.] / Architect [B.A.]
BIM Execution Plan Review - Review	Planning	Once	Client / Planning Manager [P.A.] / Project Manager [P.M.] / Project Coordinator [P.C.] / Architect [B.A.]
Planning - Design	Planning	Once	Client / Planning Manager [P.A.] / Project Manager [P.M.] / Project Coordinator [P.C.] / Architect [B.A.]
Design Authoring - Architecture	Design	Two	Client / Project Coordinator [P.C.] / Architect [B.A.]
Design Authoring - Structure	Design	Two	Client / Project Coordinator [P.C.] / Architect [B.A.] / Structural Engineer [B.S.]
Design Authoring - MEP	Design	Two	Client / Project Coordinator [P.C.] / Architect [B.A.] / MEP Engineer [B.M]
Clash Detection 01	Design	Once	Client / Project Manager [P.M.] / Project Coordinator [P.C.] / Architect [B.A.] / / Structural Engineer [B.S.] / MEP Engineer [B.M]
Clash Detection 02	Design	Once	Client / Project Manager [P.M.] / Project Coordinator [P.C.] / Architect [B.A.] MEP Engineer [B.M]
Final Federated Model - Design	Design	Once	Client / Project Manager [P.M.] / Project Coordinator [P.C.] / Architect [B.A.]
Final Federated Model - Review	Design	Once	Client / Project Manager [P.M.] / Project Coordinator [P.C.] / Architect [B.A.]
Model Deliverable Checks	Design	Once	Client / Project Manager [P.M.] / Project Coordinator [P.C.] / Architect [B.A.]
Lessons learned	Project Delivery	Once	Planning Manager [P.A.] / BIM Manager [P.M.] / BIM Coordinator [P.C.] / BIM Architect [B.A.]

8. Modelling Procedures

8.1 Classification System

To standardise the classification of the elements in the model, the ABNT NBR 15965 must be followed to assign a code.

8.2 **Modelling Criteria**

In this project, the Architectural Modelling must contain internal and external walls, roofs, doors, windows, and furniture, and must be checked for Level of Information Need compliance. The same guidelines will be followed in the Structural Modelling, which will contain the footings and the panel walls. The MEP Modelling must have elements of the water supply, specifically pipes and boilers.

8.3 **Coordinate System and Units**

- Coordinate System:

  Horizontal datum: EPSG:31983 - SIRGAS 2000

Vertical datum: Brazilian Altimetric System (BAS)

Projection: UTM zone 23K

- Units:

International System of Units: meters.

- Common point of Origin:

Decimal degrees (SIRGAS 2000):

Lat: -22.83355833°

Lon: -47.06041111°

Height: 680,00

Rotation in Map: Not allowed

All BIM models must be aligned around one Common point of Origin. This control point will serve as the fixed reference throughout all project phases. To ensure spatial consistency, all models must include a 3D target element (red pyramid upside down) and a 2D element (North and real coordinates of the project) to indicate the Common point of Origin.

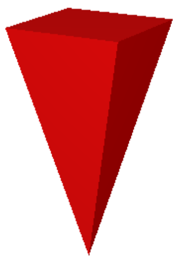


Image 01. 3D target element (red pyramid upside down).

9. Quality Control and Assurance

The major strategies to ensure model and data quality for the project validation must be MEP Employer's Information Requirements (EIR), this present BIM Execution Plan (BEP), Automated QA/QC Tools (ArchiCAD Clash detection, Model check and validation by rulesets, data verification by IDS) and the Common Data Environment (CDE) Control exchanges management. In addition, a checklist was developed to assist in checking the final model below:

GENERAL MODEL CHECKS			
Category	**Check Item**	**Status (X/✓)**	**Comments**
Information Management	Discipline-Specific Models meet defined Level of Information Need		
	File naming follows BIM Execution Plan (BEP)		
	Discipline-Specific Models are properly aligned with shared coordinates and the correct origin		
	No excessive model file size or duplicated elements		
Model Geometry & Structure	Model elements are classified as defined by the ABNT NBR 15965		
	Rooms/Spaces properly placed, named, and enclosed		
Documentation Readiness	Views/sheets are properly named and organized		
Architectural Model Checks			
Model Completeness	Doors, windows, walls, floors, roofs, and furniture correctly placed		
	Defined electrical and plumbing points		
	True North indication, terrain morphology modelling, and plateau modelling		
Code Compliance	The model complies with ABNT NBR 9050 on accessibility		
	Ventilation and natural lighting area follows ABNT NBR 15575		
	Room Data Sheets linked to room objects		
Deliverables	Floor plans, elevations, and sections use standard templates		
Structural Model Checks			
Structural Integrity	Load paths are logically modelled and consistent with the analysis		

	Structural openings coordinated with other disciplines		
	Panel placement follows the architectural project guidelines		
	Panel dimensions comply with the limits of the factory's production methods		
	The panel heights comply with the architectural design		
	Panels adhere to the recommended minimum depth of the buried base as indicated in the project specifications		
	Openings in the panels maintain the minimum required distances from edges to ensure structural stability		
	The orientation of the smooth and rough faces is clearly defined with respect to the external and internal environments		
	Complementary structures (e.g., steel framing) are coordinated and compatible with the panel system		
	All niches and installation points are accurately placed within the panels without compromising structural integrity, maintaining minimum clearances from edges and between elements		
	Concrete cover is properly dimensioned and correctly positioned		
Element Metadata	Structural elements tagged with required codes and specs		
Documentation	Structural sheets named and classified correctly		

APPENDIX 7: EXCHANGE INFORMATION REQUIREMENTS (EIR)

EIR – Exchange Information Requirements

Discipline: MEP (Mechanical, Electrical, and Plumbing)

Revision [Revision Number]

Submitted Date: [15/06/2025]

Glossary

Building Information Modelling (BIM): the process that uses a shared digital representation of a built asset to facilitate planning, design, construction, and operation. Its main goal is to provide collaboration between stakeholders to create and manage a comprehensive and data-rich model.

Common Data Environment (CDE): is a centralized digital source of information for storing, managing, and sharing project information between stakeholders. It acts as a single environment, improving collaboration and efficiency, providing security and control for all project data.

Appointment: mutually agreed instruction to provide information concerning tasks, products, or services.

Appointed Party: responsible for providing information concerning tasks, products, or services.

Appointing Party: receiver of information concerning tasks, products, or services from a Lead Appointed Party.

Delivery team: one individual or a group composed of the Lead Appointed Party and their respective Appointed Parties, responsible for project delivery activities. This may include task teams assigned to specific activities of the project.

Task team: Individuals who perform a specific task in a project.

Project team: Appointing Party and all delivery teams.

BIM Execution Plan (BEP): is a document that explains how the information management must be carried out by the delivery team.

Exchange Information Requirements (EIR): is a document that provides the information requirements related to an appointment.

Level of Information Need: a document that specifies the required information content, level of detail, and level of development that model elements must meet to ensure standardization.

1. Introduction

The main objective of this document is to define the minimum information requirements to be achieved by the MEP (Mechanical, Electrical, and Plumbing) team throughout the MEP project design, ensuring interoperability with BIM models from other disciplines, especially the architectural model, which should be the basis for all the partial models. This EIR is based on the one developed by BuildingSMART Portugal, found at https://github.com/buildingSMART-Portugal/EIR.

2. Information Requirements

2.1 Organisational Information Requirements (OIR)

The OIRs are in line with KRONAN's Mission, Vision, and Values (MVV) to support strategic decision-making and ensure alignment with its goals. The following key aspects have been identified:

- **OIR01 - Innovation and Technology Advancement:** Information to support the integration of advanced technologies and modern construction methodologies in prefabricated production.
- **OIR02 - Project Delivery and Operational Excellence:** Data related to lean construction practices and waste reduction strategies to enhance efficiency and quality of the project outcomes.
- **OIR03 - Regulatory Compliance and Sustainable Development:** Information to ensure all construction projects comply with applicable national regulations and incorporate environmentally responsible design and construction solutions.
- **OIR04 - Cost and Time Optimization:** Analytical data to guide strategic investment decisions to minimize construction time and operating and maintenance costs across the asset lifecycle.

2.2 Project Information Requirements (PIR)

2.2.1 Project Information

The following table defines the basic Study HOUSE project reference information.

Project Name	Study HOUSE
Client Names	BIM A+
Project Number	241
Project Code	SHE
Project Location	Av. José Próspero Jacobucci, 441-449 - Jardim Santa Genebra, Campinas - SP, 13086, Brazil

Contract Type/Delivery Method	**Redesign-Construction Scope**
Project Size	174,36 m²
Number of Floors	3
General Project Description	Student housing, one building, 6 House Studio units.
Start Date	16/06/2025 [DD/MM/YYYY]
Completion Date	09/09/2025 [DD/MM/YYYY]

2.2.2 Project Scope

The project involves designing and constructing a student housing facility comprising six individual studio units. The building will be constructed using prefabricated concrete wall systems. The project aims to ensure interdisciplinary coordination between the Architectural, Structural, and MEP (Mechanical, Electrical, and Plumbing) disciplines.

The MEP team contracted by the appointing party shall model and provide data for the following systems:

- Electrical system
- Plumbing and sanitary system

2.2.3 Project Phases

Phase 01: Preliminary Design - Clash Detection 01

Phase 02: Developed Design - Clash Detection 02

Phase 03: Technical Design - Final Federated Model and Project Documentation

2.2.4 Key Decision Points

Key Decision Point 1: Design Phase

Key Decision Point 2: Federated Model 01

Key Decision Point 3: Federated Model 02

Key Decision Point 4: Final Federated Model

2.3 Purposes of the Project Information Requirements (PIR)

- **PIR01 - Regulatory and Sustainability Compliance:** Provide the necessary documentation to ensure compliance with building codes, health and safety regulations, and environmental standards for precast construction.

- **PIR02 - Integrated Design Coordination:** Provide coordinated design information (federated BIM models and clash detection reports) to ensure that architectural, structural, and MEP disciplines are integrated.

- **PIR03 - Feasibility and Investment Planning:** Deliver budget estimates and construction schedules to ensure project viability in alignment with the Appointing Party's financial and operational goals.

- **PIR04 - Construction Assembly and Digital Delivery:** Supply detailed BIM data and documentation to support on-site assembly.

2.4 Table of requirements

PIR Purposes	EIR	Exchange Information Requirement (EIR)
PIR01	EIR01 - Site Context and Geolocation Data	The model must include a comprehensive representation of the terrain, capturing the property boundaries and contours (including elevation data and contour lines), existing buildings and infrastructure, utility entry points (water, sewage, electricity, telecom/data), access roads and circulation routes, vegetation and landscape features, geolocation data (true north and coordinates).
PIR02	EIR02 - Discipline Models Design	The discipline models (Architecture, Structure, MEP) must be: properly georeferenced, aligned with the Level of Information Need, submitted in IFC open format to be validated by IDS files application, and follow the naming convention.
	EIR03 - Clash Detection and Model Coordination	A federated model must be produced to coordinate disciplines. The Lead Appointed Party is responsible for running clash detection and compiling results. The issues must be solved through collaborative meetings.
PIR01 PIR02	EIR04 - BIM Compliance Validation	The Lead Appointed Party must ensure that the federated model complies with regulatory codes and the Appointing Party requirements. Also, solve all the model conflicts, coordinate Delivery Milestones and Quality through BEP and EIR Acceptance Criteria.
PIR03	EIR05 - Quantity Take-Off from Model	The quantities should be derived directly from the model geometry. The quantities must be aligned with the model's classification system following the ABNT NBR 15965. Be exported in .xlsx format for cost estimation.

PIR04	EIR06 - Design Documentation	Each discipline must submit: 2D drawings extracted from the discipline models (e.g., floor plans, sections, elevations), technical specifications, and design reports related to each discipline.
	EIR07 - Execution Support	Prepare detailed work maps and quantity maps for site use, including element breakdowns, assembly sequences, and 3D view to support on-site digitals workflows (tablet-based model navigation)

2.5 Level of Information Need

The Level of Information Need (EN ISO 7817-1:2024) reference tables focus on the Technical Design phase for the architecture, structure, and MEP disciplines. They must be followed for information exchanges between the Lead Appointed Party's delivery team members. The appointed Parties must add relevant alphanumeric information in the tables. The IFC model must also contain the same information related to the object to extract quantities.

Level of Information Need tables:

- Architectural
- Structural
- MEP

For this EIR, which specifically addresses the MEP discipline, only the MEP Level of Information Need tables are to be applied. The architectural and structural Level of Information Need tables do not apply to this exchange.

3. Acceptance Criteria

3.1 Project Information Standards

3.1.1 Standards

EN ISO 19650-2 and ABNT NBR 15965 are the standards that must be followed and considered to define how information will be exchanged, as well as its structure, classification, and process. In addition, the standards define the method used to specify the Level of Information Need.

3.1.2 Nomenclature of information containers – Files

The file names must follow ISO 19650-2 schema, as shown below:

[Project-Originator-Phase-Level-Type-Role-Number]

a. Project Code: SHE

b. Originator: KRO

c. Volume/System: XX - Not applicable

Further details on the proposed codes are listed in APPENDIX 8 of this document.

3.1.3 Metadata of information containers - Files

Metadata are additional attributes to the information containers that make it easier to locate and manage information inside the CDE environment. The metadata must follow the convention:

Status-Revision-Classification-Description-Date-Others

a. Status: consult Appendix B of this document.

b. Revision: composed of three fields according to the following definition:

<Field1>.<Field2>.<Field3>

Field1 - Single letter indicating whether the revision is Preliminary (P) or Contractual (C).

Field2 - Two numeric characters indicating the primary revision number.

Field3 - Two numeric characters indicating the version of the primary revision, exclusively used for ‘Work in Progress’.

c. Classification: must follow ABNT NBR 15965

c. Description: Brief description of the information container.

c. Date: Date of the document's last edition.

c. Others: Additional metadata if deemed necessary by the Lead Appointed Party.

3.1.4 Unit system

- International System of Units: meters and square meters (m and m²)
- The monetary unit is Real (R$).

3.1.5 Coordinate system

- Datum / Geographic CRS: SIRGAS 2000 (EPSG:4674 for latitude/longitude)
- Projected CRS: UTM Zone 23 S.

3.1.6 Information classification

Model elements are classified as defined by the ABNT NBR 15965.

3.1.7 Delivery Formats

- WIP Models: proprietary format of the platform used to be delivered at the end of each phase
- SHARED Models: IFC 4
- Exchange of information request in models: BCF
- Published Models and Documents: IFC 4, 2D Drawings in editable DWG format, PDF, and Excel tables according to predefined templates

3.1.8 Platforms and software

(CDE) AUTODOC	Architectural Model	Structure Model	MEP Model	Federated Models	2D Docs	QTO
WIP	PLN	.db1	RVT	PLN	PDF	xlsx
Shared	IFC 4	IFC 4	IFC 4	IFC 4	DWG PDF	xlsx
Published	IFC 4	IFC 4	IFC 4	IFC 4	DWG PDF	xlsx PDF

3.2 Project Information Production: Methods and Procedures

The Project information production methods and procedures define how the Appointing Party will manage and approve information.

3.2.1 Capturing information from existing assets

The Appointing Party is responsible for independently contracting the execution of the updated topographical survey. The Appointed Parties are responsible for reviewing and defining the requirements to be included in the geological-geotechnical report.

3.2.2 Creation, revision, and approval of new information

a. Information creation:

IFC Compliance: Native models must support IFC export using appropriate IFC schema classes (avoid proxy objects when a defined class exists).

Coordinate System: A shared local coordinate origin must be defined for all models. This origin may be rotated from true North and must be documented in the BIM Execution Plan (BEP), with justification.

Geometric Origin Markers: The project origin must be represented by a labelled geometric object ('OriginOfProject').

Model Consistency: All disciplines must use a common set of building story elevations and naming. Space objects must consistently reflect type, function, and room numbers. All object instances must be correctly assigned to their respective building stories. Objects with different properties (e.g., structural vs. non-structural) must be modelled as separate instances.

Classification & Duplication: The defined classification system must be used for work and quantity mapping. IFC models must avoid element duplication across disciplines.

Model Structure: All disciplines must maintain a uniform IFC model structure and follow standard naming conventions below.

IFC entity	**Nomenclature**
IfcProject	Study HOUSE
-- IfcSite	Campinas
---- IfcBuilding	Study HOUSE 01
------ IfcBuildingStorey	P00
------ IfcBuildingStorey	P01
------ IfcBuildingStorey	P02

Documentation: For BIM-generated drawings, DWG delivery is required only at the end of each project phase.

b. Coordination:

- Each Appointed Party must coordinate its models as part of quality assurance before sharing.
- BIM-related communications between the Appointing and Lead Appointed Parties should use BCF files in the Common Data Environment (CDE).
- Intra-team exchanges (within the same discipline) occur in their Work in Progress folder.

- Inter-team exchanges (between different Appointed Parties) happen in the Shared area of the CDE only after internal coordination.

- Model updates in the CDE must occur at least every 15 days, with a minimum status of S2.

c. Review and approval of information:

Each task team must perform a quality assurance check on every information container before submitting the information model within the Common Data Environment (CDE), using the Acceptance Table provided in this document as a reference.

3.2.3 Delivery of information to the Appointing Party

The final deliverables will be realised using the Autodoc CDE solution and must move to status S5 when finalised.

3.2.4 Security

All project-related information exchanges must be conducted exclusively within the Common Data Environment (CDE). No project information shall be shared through external platforms or channels without prior authorization from the Appointing Party.

3.3 Shared Resources

The IDS files for each discipline and the final architectural project submitted by the Appointing Party at the start of the design phase for the Structural and MEP disciplines, will be shared through the Common Data Environment (CDE) and must be consulted throughout this phase.

3.4 Acceptance table

GENERAL MODEL CHECKS			
Category	**Check Item**	**Status (X/✓)**	**Comments**
Information Management	Discipline-Specific Models meet defined Level of Information Need		
	File naming follows BIM Execution Plan (BEP)		
	Discipline-Specific Models are properly aligned with shared coordinates and the correct origin		
	No excessive model file size or duplicated elements		
Model Geometry & Structure	Model elements are classified as defined by the ABNT NBR 15965		
	Rooms/Spaces properly placed, named, and enclosed		
Documentation Readiness	Views/sheets are properly named and organized		
Architectural Model Checks			
Model Completeness	Doors, windows, walls, floors, roofs, and furniture correctly placed		
	Defined electrical and plumbing points		
	True North indication, terrain morphology modelling, and plateau modelling		
Code Compliance	The model complies with ABNT NBR 9050 on accessibility		
	Ventilation and natural lighting area follows ABNT NBR 15575		
	Room Data Sheets linked to room objects		
Deliverables	Floor plans, elevations, and sections use standard templates		
Structural Model Checks			
Structural Integrity	Load paths are logically modelled and consistent with the analysis		
	Structural openings coordinated with other disciplines		
	Panel placement follows the architectural project guidelines		
	Panel dimensions comply with the limits of the factory's production methods		

	The panel heights comply with the architectural design		
	Panels adhere to the recommended minimum depth of the buried base as indicated in the project specifications		
	Openings in the panels maintain the minimum required distances from edges to ensure structural stability		
	The orientation of the smooth and rough faces is clearly defined with respect to the external and internal environments		
	Complementary structures (e.g., steel framing) are coordinated and compatible with the panel system		
	All niches and installation points are accurately placed within the panels without compromising structural integrity, maintaining minimum clearances from edges and between elements		
	Concrete cover is properly dimensioned and correctly positioned		
Element Metadata	Structural elements tagged with required codes and specs		
Documentation	Structural sheets named and classified correctly		

4. Dates, Information Delivery Milestones and Control Points

Project Stage / Milestone		Estimated Start Date	Estimated Completion Date	Estimated Days of work	EIR
Design Phase					
Architectural Model	Reconstruction of the architectural project from 2D drawings to a 3D BIM model	19/06/2025	26/06/2025	7	EIR01 EIR02
Panel Structural Model	Concrete panel structural design	27/06/2025	11/07/2025	15	EIR02
Foundation Model	Foundation design	27/06/2025	11/07/2025		
MEP Model	Design of the Plumbing and Electrical Models	14/07/2025	28/07/2025	15	
Additional Projects	Complementary projects such as Photovoltaic project	14/07/2025	28/07/2025		
Federated Model 01					
Federated Model	First version of the federated model for clash detection	29/07/2025	12/08/2025	7	EIR03 EIR04
Clash Detection 01	First version of the clash detection report	13/08/2025	18/08/2025	3	
Federated Model 02					
Federated Model	Second version of the federated model for	19/08/2025	26/08/2025	7	EIR03 EIR04
Global Clash Detection	Final version of the clash detection report	27/08/2025	01/09/2025	3	
Final Federated Mode	Final version of the federated model for	02/09/2025	09/09/2025	7	

<table>
<tr><th colspan="6">Documentation phase</th></tr>
<tr><td>Panel and Foundation documentation</td><td>Final 2D and 3D Foundation documentation</td><td></td><td></td><td rowspan="3">15</td><td rowspan="3">EIR05
EIR06
EIR07</td></tr>
<tr><td>MEP Documentation</td><td>Final 2D and 3D MEP documentation</td><td>02/09/2025</td><td>09/09/2025</td></tr>
<tr><td>Additional Projects</td><td>Final 2D and 3D Additional Projects documentation</td><td>02/09/2025</td><td>09/09/2025</td></tr>
</table>

APPENDIX 8: CODES FOR NAMING INFORMATION CONTAINERS

Project-Originator-Phase-Level-Type-Role-Number

Meaning	**Code**
Project Code	SHE
Originator	KRO
Phase	**Code**
Schematic Design	SD
Design Development	DD
Construction Documentation	CD
Level	**Code**
Multiple Levels	ZZ
No Level Applicable	XX
Base Level of Building or linear Asset	L00
Floor 01	L01
Floor 02	L02
Floor 03	L03
Type	**Code**
Animation File	AF
Combined Model	CM
Specific to the clash process	CR

2d Drawing	Drawings & Models	DR
2D Model file		M2
3D Model file		M3
Model rendition file for other renditions, thermal or acoustic analysis		MR
Visualisation		VS
Bills of Quantities	Codes for Documents	BQ
Calculations		CA
Cost Plan		CP
Database		DB
Information Exchange		IE
Minutes/Action Notes		MI
Method Statements		MS
Presentation		PP
Programme		RD
Request for information		RI
Report		RP
Schedule		SH
Specification		SP
Role	**Code**	
Architect	A	

Structural Engineer	S
Electrical Engineer	E
Mechanical Engineer	M
Client	K
Sheets Number	**Code**
Architectural	A01_001, A01_00(n)
Structural	S01, S02, S03…

Status codes for the information containers within the CDE.

Description	Code
Status: Work in Progress (WIP)	
Information container being developed by the task team.	S0
Status: Shared (non-contractual)	
Information container suitable for geometric and non-geometric coordination within the delivery team.	S1
Information container suitable as a reference information for other task teams within the delivery team.	S2
Information container suitable for revision and commenting within the delivery team.	S3
Information container suitable for review and approval by the Lead Appointed Party.	S4
Information container suitable for review and acceptance by the Appointing Party.	S5
Status: Published (contractual)	
Information container authorized and accepted.	A1, An, etc

APPENDIX 9: THE LEVEL OF INFORMATION NEED

Architectural Sample

Object		*Walls*	
Appointing Party		*Building Owner*	
Apointed Party		*Architect*	
			PROJECT PHASE / DELIVERY MILESTONE:
			Technical Design
Purpose			*Generate drawings* *Visualization / Rendering* *3D coordination* *Quantity extraction and quotation*
EIR reference			*EIR 04, EIR 05, EIR 06, EIR 07, EIR 09, EIR 10, EIR 11 e EIR 12*
Minimum geometric information requirements			
Detail			*The dimensions of the element are correctly defined. Connections, links and the representation of any regions that may have an impact on coordination with other systems.*
Dimensionality			*3D*
Location			*Relative*
Appearance			*Appearance equivalent to real visualisation, with texture equivalent to the material in view.*
Parametric behaviour			*Not requested*
Minimum alphanumeric information requirements			
IFC class			*IfcWall*
Attributes			
Name			*X*
Predefined Type			*X*
Property sets			
IsExternal		*Pset_WallCommon*	*X*
Length		*Qto_WallBaseQuantities*	*X*
Width		*Qto_WallBaseQuantities*	*X*
GrossSideArea		*Qto_WallBaseQuantities*	*X*
Materials			
Name		*IfcMaterial*	*X*
Classification			
System		**Table**	
ABNT NBR 15965-4:2021		*Table 2 – Class 2C (Products – version 1.0)*	*2C 06 02 18 00 00 00*

Structural Sample

Object		*Beams*	
Appointing Party		*Building Owner*	
Apointed Party		*Structural engineer*	
			PROJECT PHASE / DELIVERY MILESTONE:
			Technical Design
Purpose			*Generate drawings Visualization / Rendering 3D coordination Quantity extraction and quotation*
EIR reference			*EIR 05, EIR 06, EIR 09, EIR 10, EIR 11 e EIR 12*
Minimum geometric information requirements			
Detail			*The dimensions of the element are correctly defined. Connections, links and the representation of any regions that may have an impact on coordination with other systems.*
Dimensionality			*3D*
Location			*Relative*
Appearance			*Appearance equivalent to real visualisation, with texture equivalent to the material in view.*
Parametric behaviour			*Not requested*
Minimum alphanumeric information requirements			
IFC class			*IfcBeam*
Attributes			
Name			*X*
Predefined Type			*X*
Property sets			
Property	**Property set**		
StrengthClass	*Pset_ConcreteElementGeneral*		*X*
ExposureClass	*Pset_ConcreteElementGeneral*		*X*
ConcreteCover	*Pset_ConcreteElementGeneral*		*X*
ReinforcementStrengthClass	*Pset_ConcreteElementGeneral*		*X*
NetVolume	*Qto_BeamBaseQuantities*		*X*
Materials			
Name			*X*
Classification			
System	**Table**		
ABNT NBR 15965-4:2021	*Table 2 – Class 2C (Products – version 1.0)*		*2C 06 02 18 00 00 00*

MEP Sample

Object			*Pipe segments*	
Appointing Party			*Building Owner*	
Apointed Party			*Delivery team*	
				PROJECT PHASE / DELIVERY MILESTONE:
				Technical Design
Purpose				*Generate drawings* *Visualization / Rendering* *3D coordination* *Quantity extraction and quotation*
EIR reference				*EIR 04, EIR 05, EIR 06, EIR 07, EIR 10, EIR 11 e EIR 12*
Minimum geometric information requirements				
	Detail			*The dimensions and position of the element are correctly defined.*
	Dimensionality			*3D*
	Localização			*Relative*
	Aparência			*Appearance equivalent to real visualisation, with texture equivalent to the material in view.*
	Comportamento Paramétrico			*Not requested*
Requisitos mínimos de informação alfanumérica				
	Classe IFC			*IfcPipeSgment*
	Attributes			
		Name		*X*
		Predefined Type		*X*
	Property sets			
		Property	**Property set**	
		NominalDiameter	*Pset_PipeSegmentTypeCommon*	*X*
		WorkingPressure	*Pset_PipeSegmentTypeCommon*	*X*
		Lenght	*Qto_PipeSegmentBaseQuantities*	*X*
	Materials			
		Name		*X*
	Classification			
		System	**Table**	
		ABNT NBR 15965-4:2021 *ABNT NBR 15965-3:2014*	*Table 2 – Class 2C (Products – version 1.0)* *Table 3 – Classification 1D – Subjects*	*2C 14 58 00 00 00 00* *1D 21 31 17 11*