WORLD CONFERENCE ON TIMBER ENGINEERING 2025
BRISBANE, AUSTRALIA
Advancing Timber for the Future Built Environment

USING THE DFMA APPROACH IN THE EARLY INTEGRATION OF ACTORS FOR THE DESIGN OF AN INDUSTRIALIZED TIMBER BUILDING – CASE STUDY

Daniela Méndez[1], Fabiana Lorca[2], Manuel Carpio[3]

ABSTRACT: Design for Manufacture and Assembly (DfMA) is a methodology that optimizes the design process to facilitate manufacturing and assembly, promoting more efficient and cost-effective construction. This study describes the process of early integration of actors in a case study of an industrialized timber building in Chile, framed in the Housing Emergency Plan. Involving architects, engineers, manufacturers, and builders from the early stages, the DfMA methodology was applied to improve communication and coordination between all actors. Five design stages were identified based on the RIBA guide, and BIM and modeling tools were used to integrate information from all participants. The results indicate that, although design time increases, production is more efficient, with fewer errors and rework, and higher construction quality. This study provides a framework for future projects in the construction industry, highlighting the importance of early integration and use of digital tools. Future work should validate time and cost savings, reduction in waste, improvement in quality and processes in manufacturing and construction phases.

KEYWORDS: Design for Manufacture and Assembly DfMA, Industrialized Construction, timber construction, early integration, stakeholders.

1 – INTRODUCTION

Design for Manufacture and Assembly (DfMA) is an approach aimed at optimizing the design process to facilitate the fabrication and assembly of components [1]. Its implementation in architecture and engineering, in conjunction with Building Information Modelling (BIM), enables the reduction of costs and construction timelines by enhancing the integration between design and construction. This is achieved through standardization, simplification of components, and modular design from the early stages of the project [2], [3], [4].

In the context of industrialized timber construction, the DfMA approach plays a critical role, as it enables the fabrication of structural components in controlled and safe environments. This not only ensures precisely dimensioned elements that facilitate on-site assembly but also streamlines processes to enhance productivity by reducing labour demands and on-site construction time. Additionally, it contributes to higher quality standards and minimizes waste generation [5]. However, for its progressive adoption, it is essential to advance in standardization and capacity building to enable effective implementation [6].

A key component of the DfMA approach is the early integration of stakeholders, as interdisciplinary collaboration enables more effective management of construction process challenges. In industrialized timber construction projects—where prefabrication and on-site assembly demand high levels of precision—early integration is based on five core principles: (i) multidisciplinary coordination [7], to ensure seamless communication among stakeholders; (ii) identification of needs, to align design and production expectations; (iii) problem prevention, through early detection of clashes and technical constraints; (iv) enhancement of

[1] Daniela Méndez López, Centro Nacional de Excelencia para la Industria de la Madera (CENAMAD); School of Civil Construction, Faculty of Engineering, Pontificia Universidad Católica de Chile, Santiago, Chile, dmendez1@uc.cl.

[2] Fabiana Lorca, Centro Nacional de Excelencia para la Industria de la Madera (CENAMAD), Pontificia Universidad Católica de Chile, Santiago, Chile, fllorca@uc.cl.

[3] Manuel Carpio, Centro Nacional de Excelencia para la Industria de la Madera (CENAMAD); Department of Construction Engineering and Management, School of Engineering, Pontificia Universidad Católica de Chile, Santiago, Chile; manuel.carpio@uc.cl; and Department of Construction Engineering and Project Management, University of Granada, Spain carpio@ugr.es.

https://doi.org/10.52202/080513-0110

sustainability, by optimizing resource use and minimizing waste; and (v) development of an integrated approach [8], in which design and production decisions are reached collaboratively to improve overall project efficiency.

This paper aims to describe and analyse the process of early integration of key stakeholders in the development of an industrialized construction project in Chile, emphasizing the technical challenges encountered and the methodological and digital tools employed to enable such integration. Special attention is given to the implementation of collaborative approaches from the early design stages, in alignment with DfMA principles, and to the use of BIM methodologies to facilitate interoperability, interdisciplinary coordination, and informed decision-making.

This study examines a case of DfMA application in a mid-rise timber building, developed within the framework of Chile's Housing Emergency Plan [9]. This programme aims to address the increasing demand for sustainable and rapidly deployable housing solutions. The early integration of stakeholders through the DfMA approach enables greater efficiency in the design process, reduces fabrication and assembly time, and ensures improved construction quality.

This study seeks to provide a reference framework for future projects, optimising collaboration in the design and execution of timber buildings developed under the DfMA approach.

2 – BACKGROUND

DfMA comprises Design for Manufacture (DfM) and Design for Assembly (DfA), with the former referring to the production of components and the latter to their method of assembly [10]. In the context of construction, DfA involves design strategies aimed at minimising on-site work, while DfM enables specialists to fabricate key project elements within a controlled factory environment [11].

Several studies have explored the implementation of DfMA in construction, highlighting its potential to enhance the sector's efficiency and productivity. Gao et al. [1] identified that adopting DfMA can reduce construction time and costs through a more streamlined design that facilitates the manufacture and assembly of prefabricated components. Lu et al. [2] examined the integration of DfMA with other methodologies, such as lean construction and BIM, emphasising how these synergies can improve coordination across project phases. Jin et al. [12] highlight that applying DfMA in prefabricated timber buildings allows for maximised structural efficiency, reduced material waste, and improved component traceability. Similarly, Tan et al. [4] underscore the need for specific regulations to support the adoption of DfMA in timber construction, promoting standardisation and modularisation of building systems. Nonetheless, the implementation of DfMA in the construction sector still faces challenges, such as limited training and resistance to change among stakeholders, which hinders its widespread adoption. Despite these barriers, the growing interest in industrialised timber construction and its alignment with circular economy strategies reinforce the importance of continued research into the integration of DfMA to maximise its impact on efficiency, sustainability, and carbon emissions reduction [3].

The implementation of DfMA requires the early integration of multiple stakeholders during the design phase to optimise the manufacturing and assembly of components. According to Razak et al. [3], collaboration among designers, engineers, manufacturers, and contractors enables the early identification of challenges and opportunities, thereby reducing the need for later modifications and improving overall project efficiency. In this context, the use of BIM facilitates interdisciplinary coordination by providing digital models that support the simulation of construction processes and the traceability of components. Furthermore, certain procurement methods promote this integration by involving the contractor during the design stage, which streamlines decision-making and enhances the implementation of prefabrication strategies.

Unlike traditional processes - where design and construction are often carried out sequentially and in a fragmented manner - DfMA promotes a more integrated and efficient approach. In conventional methods, the lack of communication between designers and contractors can lead to conflicts during execution, resulting in costly redesigns, delays, and material waste. Moreover, the integration of digital technologies such as BIM enhances information management, minimising errors and improving the planning of construction activities. In this way, the adoption of DfMA represents a shift towards a more industrialised construction model, where early planning and interdisciplinary collaboration are fundamental to project success.

3 – PROJECT DESCRIPTION

For the design of an industrialised timber building, developed under Chile's Housing Emergency Plan, the DfMA approach was implemented to promote the early integration of architects, engineers, specialists,

https://doi.org/10.52202/080513-0110

manufacturers, and contractors. This approach enabled the optimisation of the design, facilitated the manufacturing and assembly processes, and improved communication and coordination among the stakeholders involved. The project consisted of a mid-rise residential building of four storeys, based on a platform-frame system composed of lightweight timber frame panels. The building comprises 16 housing units, arranged into two typologies of 60.5 m², each including a living room, dining area, three bedrooms, one bathroom, a kitchen, and a utility area, with a total built area of 968 m² for residential units and 1,150 m² including circulation spaces.

The design prioritised prefabrication, using BIM to coordinate disciplines, ensure interoperability between parametric models, and maintain control over project information, such as prefabricated component specifications, quantity take-offs, documentation, integration of MEP ducts, and associated costs. Furthermore, standardisation in the design was encouraged through continuous monitoring of project elements. This also enabled the development of a clear assembly sequence, considering the installation of panels, connectors, and all finishing components to be integrated on site.

Various construction strategies compatible with prefabrication were incorporated to meet the hygrothermal performance standard, including measures to improve thermal transmittance, reduce air infiltration, control condensation, and enhance ventilation efficiency. Additionally, criteria related to energy efficiency, acoustic insulation, and fire resistance were implemented. In terms of digital modelling and coordination, a federated BIM model was employed, integrating tools such as Revit, Cadworks, and Navisworks, based on an Information Delivery Specification (IDS) [13], which structured the exchange of information and facilitated interdisciplinary management. This approach enabled the optimisation of the design process and allowed for construction simulation, supporting early-stage error detection when the cost of design changes is significantly lower compared to modifications during the construction phase.

Figure 1. The building under study is presented in its final form, showcasing industrialised components and a timber structural system.

4 – DESIGN PROCESS

A study was carried out to investigate forms of early stakeholder involvement in a project, leading to the definition of eight project stages based on the RIBA Plan of Work: (i) strategic definition, where the client's need is identified; (ii) preparation and briefing, which establishes the project's regulatory, technical, and physical feasibility; (iii) concept design; (iv) spatial coordination; (v) technical design; (vi) manufacturing and construction; (vii) handover; and (viii) use. Although the primary focus lies on the design stages (Stages 0 to 4), the subsequent stages - manufacturing and construction, handover, and use (Stages 5 to 7) - were also documented to understand their articulation with the industrialised design process. For each proposed design stage, a set of tasks was defined for the various stakeholders involved, and the BIM methodology, along with modelling tools such as Revit and CadWorks, was used to integrate information from all project areas [11].

At each design stage, the corresponding interactions between stakeholders and the number of iterations were recorded, with the aim of proposing a methodology to reduce the number of iterations and accelerate the design process.

Stage 0 – Strategic Definition: At this stage, opportunities are identified, and the strategic guidelines of the project are established. As the case study is framed within the Housing Emergency Plan, the design involves a standardised industrialised building that can be adapted to different locations and cities. Consequently, it must be aligned with the specific technical requirements of various regions and comply with the minimum industrialisation criteria, ensuring at least 50% prefabrication.

The project adopts a Type 2 Modern Method of Construction (MMC), based on 2D panel systems. These structural panels are pre-assembled in the factory with integrated electrical installations, allowing the project to achieve an estimated prefabrication level exceeding 60%. This strategy aims to optimise on-site assembly times while reducing errors and clashes.

This stage is undertaken jointly by the architectural firm and the industrialised construction company, involving the evaluation of the project's technical and economic feasibility. It is also essential to identify the client's specific requirements, as well as opportunities to apply DfMA principles to optimise the design for ease of manufacturing, assembly, and potential future adaptation or reuse. As part of a comparative analysis with previous DfMA project experiences, significant improvements in efficiency and outcomes have been identified. One of the most consistent benefits is the reduction in construction time, with studies reporting savings ranging from 20% to 60% in overall project schedules [14], including cases where the entire structure was erected in just nine weeks, as demonstrated in Brock Commons [15]. Furthermore, early standardisation and coordination have enabled labour productivity gains of up to 46.6%, as evidenced by the VAP system in Chile [16], along with a general efficiency increase of 13.5% in projects that adopt DfMA as a core approach [11].

Regarding economic and environmental impacts, the literature indicates that DfMA can reduce construction costs by between 15% and 35%, while also decreasing on-site labour requirements by up to 75% [17], [18]. In terms of sustainability, waste reductions of between 50% and 68% have been reported [16], along with carbon emission reductions of up to 25% [17], positioning DfMA as a key strategy for low-carbon construction. Improvements in design have also been documented, such as a 33% reduction in the number of components [19], contributing to greater precision and a decrease in errors and clashes on site. These findings support the adoption of DfMA in industrialised housing projects such as the one presented in this case study.

Stage 1 – Preparation and Briefing: This stage focuses on identifying and validating opportunities to apply DfMA within the project, with the aim of increasing standardisation and facilitating manufacturing and assembly processes. A central strategy involves reducing the number of distinct components, promoting the repetition of elements such as walls, floor slabs, window types, and door types. This measure not only optimises the design for manufacture but also significantly reduces the likelihood of errors, rework, and on-site clashes.

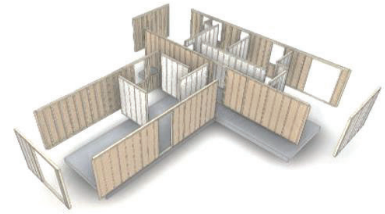

Figure 2: overview of panels

Table 1: quantity of prefabricated panels by type.

Panel type	External wall panel	Partition wall panel	Floor panel	Roof panel	Internal wall panel
Panel 01	16	-	-	-	-
Panel 02	16	-	-	-	-
Panel 03	16	-	-	-	-
Panel 04	8	-	-	-	-
Panel 05	16	-	-	-	-
Panel 06	-	16	-	-	-
Panel 07	-	8	-	-	-
Panel 08	-	8	-	-	-
Panel 09	-	16	-	-	-
Panel 10	-	-	16	-	-
Panel 11	-	-	16	-	-
Panel 12	-	-	16	-	-
Panel 13	-	-	16	-	-
Panel 14	-	-	-	16	-
Panel 15	-	-	-	16	-
Panel 16	-	-	-	16	-
Panel 17	-	-	-	16	-
Panel 18	-	-	-	-	16
Panel 19	-	-	-	-	16
Panel 20	-	-	-	-	32
Panel 21	-	-	-	-	16
Panel 22	-	-	-	-	64
Panel 23	-	-	-	-	16
Panel 24	-	-	-	-	16

During this stage, the incorporation of MMC Type 2 is quantified, referring to the use of 2D panels preassembled in the factory with integrated electrical and plumbing systems. This reinforces the prefabrication approach and facilitates technical coordination in subsequent phases. Additionally, the capacity of the supply chain is assessed to ensure that industrialised solutions can be effectively implemented using locally available resources and within the projected timelines.

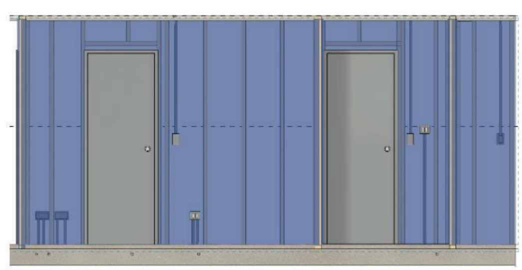

Figure 3: elevation view of 2D panel with electrical installations.

The architecture team, the industrialised construction company, and the structural engineering team actively participate in this stage, collaborating from the outset to

https://doi.org/10.52202/080513-0110

ensure that the design meets the technical and logistical requirements of the construction system. The outcome of this stage is a coordinated preliminary design, which provides the foundation for the detailed development of the project.

Stage 2 – Concept Design: In this stage, the conceptual design of the project is developed, establishing the technical and strategic foundations that will guide its further development. Key aspects are defined, such as clear heights, structural spans, spatial layout, and the number of rooms or housing units required, considering both functional criteria and the constraints of the industrialised construction system. A preliminary construction plan and an initial cost estimate are also developed, along with the integration of sustainability strategies related to energy efficiency, materials, and waste management.

This stage involves coordinated work between the architecture and structural engineering teams, electrical and plumbing specialists, and the industrialised construction company, ensuring that the conceptual design aligns with DfMA principles and is compatible with the 2D panel construction system that integrates electrical and plumbing installations directly from the factory.

Stage 3 – Spatial Coordination: During this stage, spatial coordination among the various disciplines is carried out to ensure the geometric and technical compatibility of all project systems. Key aspects considered include the assembly sequence, manufacturing and assembly tolerances, and the updating of the cost plan in collaboration with contractors, incorporating more precise information on materials, quantities, and construction logistics.

To facilitate coordination, a federated model was employed—this refers to a structure that links discipline-specific models (architecture, structural, electrical, plumbing) without merging them into a single file, enabling joint review. This methodology aligns with the findings of Erdem and Becerik [20], who compared centralised and federated modelling approaches and demonstrated that the federated approach led to a 29% improvement in productivity, a 24% reduction in rework, and a 10% decrease in total project duration. These benefits are attributed to the ability of disciplines to work in parallel, retain autonomy over model development, and detect conflicts early through collaborative platforms such as Navisworks, which was used in this project for coordination purposes.

Figure 4: 3D model used for coordination as viewed in Navisworks.

A key aspect was the reduction of cuts and perforations in timber structural elements for the passage of services, made possible through the early detection of clashes using the federated model. This optimisation enabled a higher level of panel prefabrication by integrating electrical and plumbing ducts from the design phase, with the aim of streamlining manufacturing and assembly processes during on-site execution.

The architectural, electrical, and plumbing models were developed in Revit, using a shared version and a common BIM Information Delivery Specification. The structural model was developed in Cadworks and exported in IFC format, configured to integrate all parameters and model information into the federated model. This integration posed interoperability challenges due to differences between modelling platforms, making the use of the Information Delivery Specification particularly important. It defined common criteria for naming conventions, file formats, origin point, level naming, and materials. These tools were essential for ensuring interoperability and consistency across models.

Furthermore, the contractor was incorporated early in this stage, allowing the construction sequence to be conceived based on the actual logic of on-site assembly. This involvement enabled validation of the component installation order, hoisting operations, and logistical planning, thereby integrating technical and construction decisions directly from the design phase.

Stage 4 - Technical Design: In this stage, the complete technical documentation required for the fabrication and construction of the project is developed. All necessary drawings and technical specifications are consolidated, including structural calculation reports, detailed plans, component breakdowns, assembly sequences, quantity take-offs, budgets, and construction schedules. Of particular importance is the precise specification of structural and assembly connectors, taking into account both compatibility with the prefabricated system and compliance with regulatory and performance requirements.

The documentation produced includes:

- Plans and construction details for architecture, structure, and MEP systems.
- Shop drawings for prefabricated elements.
- Construction planning and a Gantt chart outlining a differentiated and coordinated sequence between prefabricated and in-situ components.
- A detailed assembly sequence.
- Component breakdowns for structural and envelope elements.
- Quantity take-offs for materials and components.
- A detailed cost estimate.
- 3D visualisations, including renderings and construction details.

During this phase, it is also ensured that the design complies with hygrothermal and acoustic requirements, in accordance with regulatory standards and project specifications.

Stage 5 – Manufacturing and Construction: This stage marks the transition from technical design to execution, beginning with the fabrication of prefabricated components. To ensure correct implementation, it is recommended to establish a monitoring plan covering manufacturing, packaging, logistics, and delivery. This plan should include quality control protocols, traceability measures, and coordination with on-site assembly processes.

As a complementary strategy, it is advisable to develop a full-scale or partial mock-up of the construction system to validate the design, connection systems, and assembly procedures in a controlled environment. Moreover, this prototype can serve as a training tool for the workforce, familiarising them with the logic of industrialised assembly and thereby contributing to greater efficiency during the construction stage.

Stages 6 and 7 – Handover and Use: These stages correspond to the period following construction, during which the building's care, proper functioning, and maintenance must be ensured. At the handover stage, all relevant technical information should be provided to support the building's operation, including manuals, updated drawings, and maintenance protocols.

During the use stage, it is important that both technical teams and users are able to provide feedback on the building's performance. It is also recommended to consider the implementation of digital twins as a tool to support operational management, enabling real-time monitoring of the building's behaviour and the planning of maintenance tasks.

The figure presents a sequential diagram of the project's first five design stages, organised according to the RIBA methodology—from strategic definition through to technical design. For each stage, the main stakeholders involved are identified, along with the corresponding outputs, such as the preliminary design, discipline-specific models, the federated BIM model, and the complete set of technical deliverables. The diagram illustrates the increasing interdisciplinary integration of the design team, as well as the progressive use of BIM tools that support the transition from initial planning to detailed and documented technical coordination. Furthermore, it highlights the involvement of the industrialised construction company and the contractor at key stages to ensure alignment between design and execution.

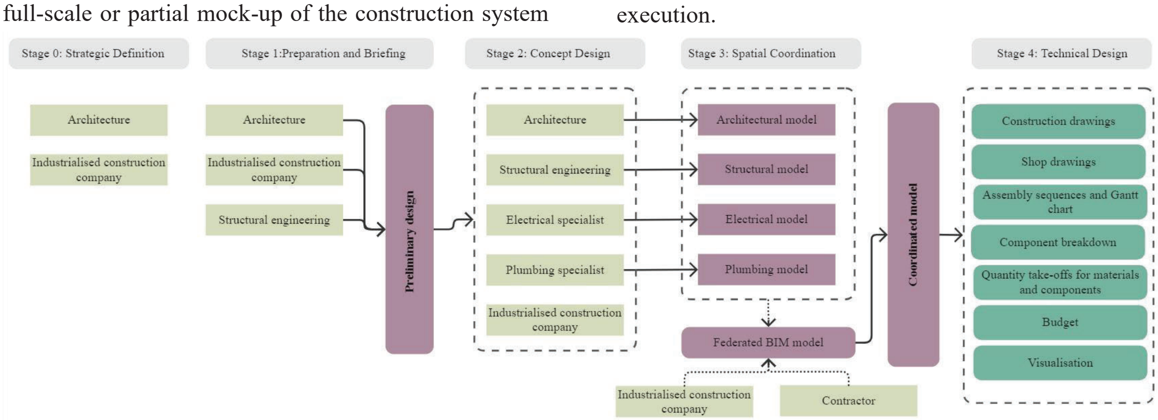

Figure 5. Diagram of design stages (0 to 4) showing involved stakeholders and partial project outputs.

https://doi.org/10.52202/080513-0110

5 – RESULTS

The implementation of DfMA in this case study followed a sequential logic based on the stages outlined in the RIBA framework [11]. However, during the project's development, it became evident that this linear approach may constrain opportunities for simultaneous collaboration and early feedback - particularly in Stage 3: Spatial Coordination, where most of the design conflicts and model adjustments were concentrated. As illustrated in the figure, each discipline develops an individual model that serves as input for the federated model. This is followed by a review conducted by the industrialised construction company and the contractor, aimed at identifying clashes at a minimum of three key stages. Subsequently, design optimisation is carried out, which in turn updates the models and generates additional iterations.

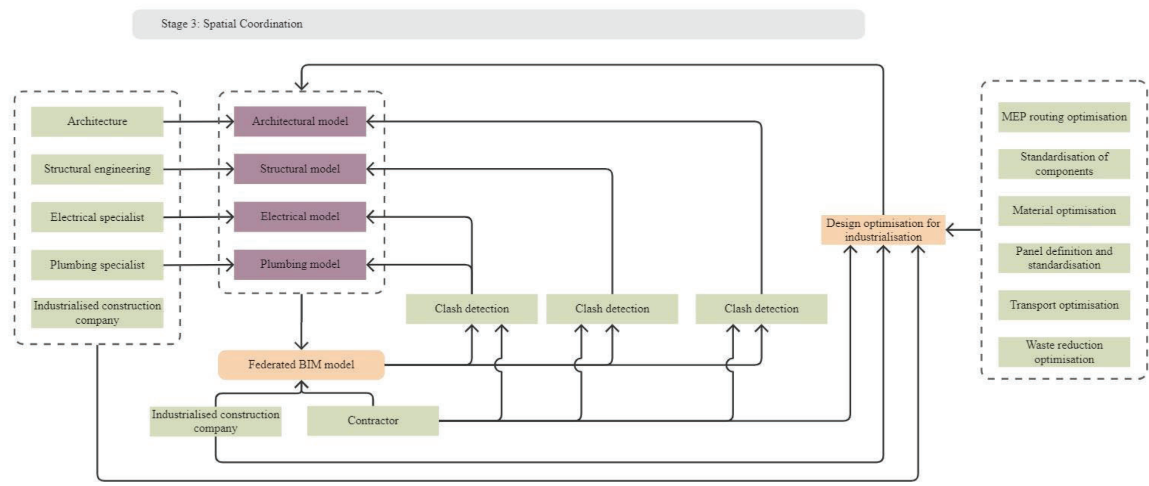

Figure 6. Diagram of Stage 3, showing that from Stage 2 onwards each stakeholder develops their respective model.

Based on this experience, which involved over 3,500 hours of collaborative work, it is proposed that future projects could benefit significantly from more integrated and parallel approaches, such as those promoted by Integrated Concurrent Engineering (ICE). This methodology enables simultaneous decision-making across disciplines by fostering real-time, coordinated work sessions, thereby reducing iteration cycles. Its application would have a direct impact on optimising the hours dedicated to federated model coordination, particularly by reducing the workload burden on the contractor.

Furthermore, it is recommended that design optimisation for industrialisation should not occur in parallel with modelling, but rather as a preliminary stage. This would allow for the establishment of shared criteria and the structuring of the model based on DfMA strategies from the outset. In this regard, it is essential to define a design freeze at the end of Stage 2 (Concept Design), clearly identifying which project elements will remain unchanged. This enables subsequent progression into the coordination and technical design stages with greater certainty, efficiency, and coherence across disciplines.

The following diagram illustrates the proposed workflow, in which each stakeholder - together with the contractor - participates in the design optimisation for industrialisation as a preliminary stage prior to the development of individual models. Once this common framework is established, each discipline produces its own specific model, which is subsequently integrated into the federated model. From this integration, a collaborative coordination session is conducted, involving the entities responsible for each model, during which potential clashes are identified and resolved - always maintaining DfMA - driven design optimisation as the central guiding principle.

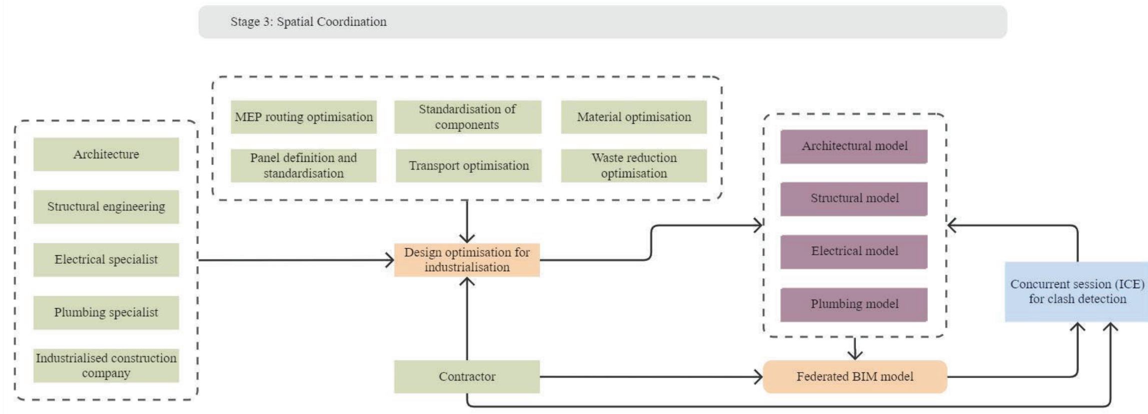

Figure 7. Proposed diagram of Stage 3, showing that from Stage 2 onwards each stakeholder becomes actively involved.

Another key aspect identified is the need for contracts to reflect this new way of working, recognising the importance of early integration and concurrent engineering processes. Under traditional contractual frameworks, adequate time and responsibility are not always allocated for these collaborative phases, which limits the effective application of DfMA principles. Therefore, it is recommended that contractual clauses be established to promote collaboration from the early stages of design. It is also essential that all stakeholders are proficient in the digital tools used - such as Revit - and that a clear protocol exists for the generation, exchange, and delivery of information, including naming conventions, file formats, and version control.

Finally, although the design process required a high level of resource commitment in the early stages - particularly in modelling activities, interdisciplinary coordination, and iteration development using BIM tools - it is expected that this early integration will lead to a more efficient construction phase, with a lower likelihood of errors, rework, and deviations. Owing to the early involvement of key stakeholders, greater certainty was achieved in relation to the construction process, budget, and schedule (Gantt chart), all of which were iterated and validated during the design phase. While the results from the completed construction are not yet available, the work carried out has laid a solid foundation for optimising cost, time, and quality in the subsequent stages.

6 – CONCLUSION

The implementation of DfMA and the early integration of stakeholders in the design of an industrialised timber building demonstrated that it is possible to standardise communication processes during the design stages, enabling the early resolution of issues and creating the conditions for greater efficiency and quality in the subsequent manufacturing and construction phases. The use of digital tools, such as BIM models developed in Revit and Cadworks, proved essential in aligning the interests and objectives of the various participants through continuous, shared, and updated visualisation of the project.

This experience enabled the structuring and management of collaboration within a complex project, by distributing responsibilities across stages, establishing information delivery protocols, and clearly defining the expected contributions of each discipline. It highlights the need to move towards more collaborative and parallel working models, supported by contracts that enable concurrent engineering, as well as cross-disciplinary training in digital technologies - an essential condition for ensuring information quality and traceability.

Looking ahead, the project is expected to continue being monitored, particularly during the manufacturing and construction phases, in order to quantify the benefits of early integration and DfMA application in terms of time, cost, quality, and process reduction. Furthermore, this experience provides a foundation for reducing design times in future projects through the development of key question checklists, observations, and stage-specific responsibilities that can guide decision-making and enhance process efficiency from the outset.

7 – ACKNOWLEDGMENTS

This work was funded by the National Agency for Research and Development (ANID) / Scholarship Program / DOCTORATE SCHOLARSHIPS CHILE / 2023-21230820; ANID BASAL FB210015 CENAMAD; BG23/00134; and Pontificia Universidad Católica de Chile through the 2024 International Sabbatical Support Competition of the Academic Vice-Rectorship.

https://doi.org/10.52202/080513-0110

8 – REFERENCES

[1] S. Gao, R. Jin, and W. Lu, “Design for manufacture and assembly in construction: a review,” Building Research & Information, vol. 48, no. 5, pp. 538–550, Jul. 2020, doi: 10.1080/09613218.2019.1660608.

[2] W. Lu et al., “Design for manufacture and assembly (DfMA) in construction: the old and the new,” Architectural Engineering and Design Management, vol. 17, no. 1–2, pp. 77–91, 2021, doi: 10.1080/17452007.2020.1768505.

[3] M. I. A. Razak, M. A. Khoiry, W. H. W. Badaruzzaman, and A. H. Hussain, “DfMA for a Better Industrialised Building System,” Jun. 01, 2022, MDPI. doi: 10.3390/buildings12060794.

[4] T. Tan et al., “Construction-Oriented Design for Manufacture and Assembly Guidelines,” 2020, doi: 10.1061/(ASCE)CO.1943.

[5] Building and Construction Authority (BCA), “Desingn for Manufacturing and Assembly (DfMA) Mass Engineered Timber,” Singapore, Sep. 2018.

[6] J. Thinley and S. Hengrasmee, “Innovating Bhutan’s residential construction with mass timber for economic and environmental sustainability,” Journal of Building Engineering, vol. 78, no. September, p. 107763, 2023, doi: 10.1016/j.jobe.2023.107763.

[7] V. Laovisutthichai, W. Lu, and S. S. Y. Lau, “Design for Excellence in Architecture, Engineering, and Construction: A Multi-stakeholder Model,” 2022, pp. 737–750. doi: 10.1007/978-981-19-5256-2_58.

[8] A. C. M. Barbosa, B. A. F. Figueiredo, and P. J. S. Cruz, “Life cycle assessment for prefabricated buildings: a state of the art for enhancing construction circularity,” 2023.

[9] Ministerio de Vivienda y Urbanismo, “Plan de Emergencia Habitacional 2022-2025,” Jul. 2022.

[10] R. Bogue, “Design for manufacture and assembly: Background, capabilities and applications,” Assembly Automation, vol. 32, no. 2, pp. 112–118, Apr. 2012, doi: 10.1108/01445151211212262.

[11] RIBA, “DfMA Overlay to the RIBA Plan of Work - Mainstreaming design for manufacture and assembly in contruction - 2nd Edition,” London, 2021.

[12] R. Jin, S. Gao, A. Cheshmehzangi, and E. Aboagye-Nimo, “A holistic review of off-site construction literature published between 2008 and 2018,” Nov. 20, 2018, Elsevier Ltd. doi: 10.1016/j.jclepro.2018.08.195.

[13] BIM Loket and BuildingSMART, “IDS Básica BIM Edificación v2.0,” 2022. [Online]. Available: https://www.buildingsmart.es/recursos/manual-de-entrega-de-información-edificación/

[14] C. Langston and W. Zhang, “DfMA: Towards an integrated strategy for a more productive and sustainable construction industry in Australia,” *Sustainability (Switzerland)*, vol. 13, no. 16, Aug. 2021, doi: 10.3390/su13169219.

[15] M. Kasbar, S. Staub-French, A. Pilon, E. Poirier, Z. Teshnizi, and T. Froese, “Construction productivity assessment on Brock Commons Tallwood House,” *Construction Innovation*, vol. 21, no. 4, pp. 951–968, Oct. 2021, doi: 10.1108/CI-11-2019-0118.

[16] H. Hernández, F. Ossio, and M. Silva, “Assessment of Sustainability and Efficiency Metrics in Modern Methods of Construction: A Case Study Using a Life Cycle Assessment Approach,” *Sustainability (Switzerland)*, vol. 15, no. 7, Apr. 2023, doi: 10.3390/su15076267.

[17] C. Widanage and K. P. Kim, “Integrating Design for Manufacture and Assembly (DfMA) with BIM for infrastructure,” Nov. 01, 2024, *Elsevier B.V.* doi: 10.1016/j.autcon.2024.105705.

[18] S. Jung and J. Yu, “Design for Manufacturing and Assembly (DfMA) Checklists for Off-Site Construction (OSC) Projects,” *Sustainability (Switzerland)*, vol. 14, no. 19, Oct. 2022, doi: 10.3390/su141911988.

[19] C. V. Ferreira, F. L. Biesek, and R. K. Scalice, “Product innovation process: a model based on manufacturing readiness level (MRL), design for manufacturing and assembly (DfMA) and technology readiness level (TRL),” Editora Edgard Blucher, Ltda., Nov. 2019, pp. 475–489. doi: 10.5151/cbgdp2019-36.

[20] A. Erdem and G. T. Becerik, “A Comparison of Two BIM Collaboration Practices During the Design Phase of Construction Projects Using a Hybrid Simulation Technique,” in *11th INTERNATIONAL CONFERENCE ON COMPUTATIONAL AND EXPERIMENTAL SCIENCE*, 2024.