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Modeling Intra-Organization Fragmentation and Integration to Enhance Performance in Industrialized Timber Construction

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Abstract

Industrialized construction faces persistent fragmentation challenges that negatively impact project performance. Although there is consensus on the importance of integration, its effective adoption in industrialized construction, particularly for modular timber building companies, remains underexplored. This study examines how intra-organization fragmentation and stakeholder integration influence project performance through a combined empirical case study and theoretical simulation analysis. This study adopted a computational modeling strategy based on the Virtual Design Team (VDT) approach to simulate the organizational structure and process in a real-world industrialized timber building company. The VDT's baseline results reveal significant rework from inadequate early integration among specialties and functional departments, increasing the project schedule. A revised scenario introduces horizontal and vertical integration by co-locating design and manufacturing team members and reducing the decision-making level. These adjustments substantially reduced rework in design phases and shortened the project duration below the original plan. The critical role of early collaborative involvement of all disciplines emphasizes that integrated organizational structures and processes are essential for ensuring reliable project outcomes in industrialized timber building companies. This research provides empirically grounded insights highlighting the strategic importance of integration in industrialized construction and establishes a validated modeling basis to guide practical interventions and future research on integration-driven improvements.

Keywords: industrialized construction; integration; fragmentation; intra-organization

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1. Introduction

Industrialized construction, as a promising path forward, is helping the construction industry transition toward more innovative and efficient practices. Industrialized construction encompasses various concepts—such as "modular construction," "prefabricated construction," "off-site construction," "industrialized building systems," and "modern methods of construction"—all of which refer to applying manufacturing techniques to construction [1–3]. These techniques can involve creating two-dimensional components

(e.g., panels for walls, ceilings, floors, or beams) or three-dimensional volumetric modules ready for use with finishes, electrical wiring, plumbing, and even furniture fixtures [1,4,5].

Such processes allow for the mass production of building components in a controlled environment—either entirely off-site or in a combination of on-site and off-site fabrication [1]. Once produced, these components and modules are transported and assembled on the construction site with minimal additional on-site work [6]. Manufacturing under controlled conditions yields multiple advantages, including higher quality through standardized processes [1,3,7–10], potential time and cost savings due to faster assembly compared with traditional construction, improved safety, and reduced on-site labor [1,8–11]. Additionally, materials can often be shared across projects, further diminishing waste [2,8,10].

Achieving these benefits in industrialized construction, however, demands collaboration and coordination among project stakeholders and the alignment of processes [6,9,12]. Seminal works identified integration as a critical success factor in industrialized construction projects [5,6,9,13] and highlighted its absence as a significant barrier to achieving the successful application of industrialized construction [8,12,13].

Within the construction sector, integration primarily involves coordinating the project's activities [14]. This entails creating an environment where key stakeholders—from owners and designers to contractors—collaborate as early as possible across a project's entire lifecycle, sharing information, aligning objectives, and forming a cohesive team culture [15–17]. A high level of team integration has been shown to improve team behavior and project outcomes [18] while reducing schedule growth [18,19]. Early integration further addresses uncertainty through more frequent communication and co-location [20] and allows the incorporation of requirements from the initial design phase through to fabrication, consequently reducing the occurrences of reworks that impact project performance [13].

Despite these recognized benefits, the construction industry remains highly fragmented [2,3,6,15,17,21–25]. The prevalence of discrete project phases and traditional project delivery methods (e.g., design–bid–build) often isolates design activities from construction execution, undermining the early integration and collaboration among stakeholders needed for efficient information flow [23,24,26]. Consequently, it is difficult to achieve a degree of coordination sufficient to prevent costly misunderstandings or slow decision making [13,21].

Recent studies on industrialized construction have primarily focused on identifying risk factors, success drivers, or barriers to its implementation [6,9,10,13]. However, fewer works have addressed integration at a conceptual level or limited their analysis to specific aspects, such as individual project phases or stakeholder relationships, without fully capturing how fragmentation and integration evolve across organizational structures and process workflows within industrialized companies. For instance, Ekanayake et al. [27] used Social Network Analysis (SNA) to characterize the relationships among stakeholders in industrialized projects, highlighting the need for proper collaborative information exchange and better coordination without analyzing how these interactions affect project performance. Wang et al. [28] developed a framework to evaluate organizational resilience in prefabricated construction projects by identifying and managing relationships among stakeholders at each project stage. However, their work did not study the process-level impact of stakeholder coordination. Hyun et al. [29] emphasized that adopting integrated design processes in modular construction reduces rework. However, their analysis was limited to design phase integration. These isolated findings illustrate the need for more comprehensive and methodologically robust research on fragmentation and integration in industrialized construction.

Against this knowledge gap, this study aims to examine the impact of intra-organization fragmentation and stakeholder integration—owners, designers, subcontrac-

tors, and suppliers—on the project performance of an industrialized timber building company, using a combination of empirical case study and theoretical simulation analysis. The authors study how stakeholders interact throughout the definition, design, and manufacturing process and how this interaction (integration or fragmentation) impacts the project performance. To achieve this goal, the authors adopted the Virtual Design Team (VDT) approach to simulate the organization and process of a Chilean industrialized timber building company. The VDT is a modeling and simulation paradigm that has been widely applied to analyze organizational structures, workflows, and communication patterns [17,30,31].

This study contributes practical insights and evidence-based guidance on modeling and optimizing fragmentation and integration within industrialized building companies. By grounding the analysis in a real-world case and applying a validated simulation approach, we produced actionable knowledge and strategies that project stakeholders can directly implement or adapt to enhance coordination, reduce rework, and improve project delivery performance. We kept refining the VDT model to achieve more generalizable results and do not pretend to generalize them with this first study.

This paper comprises six sections. In the second section, the paper introduces a background of fragmentation and integration in the Architectural, Engineering, and Construction Industry and Virtual Design Team (VDT). Then, we explain the methodology to create, validate, and simulate the VDT model. The fourth section presents the simulation results of the VDT. Finally, sections five and six present the discussions and conclusions of this study.

2. Background

2.1. Fragmentation and Integration in the Architectural, Engineering, and Construction Industry

In the Architectural, Engineering, and Construction (AEC) industry, fragmentation frequently stems from the complexity of projects and the high degree of specialization, which hinders effective collaboration by generating multiple handoffs and unclear accountability [23,24]. While specialization enhances technical expertise, it also increases the risk of organizational silos and poor information flow [23]. Fragmentation becomes more pronounced when individuals or teams work in isolation with minimal coordination, impeding the overall cohesion of project efforts [32].

Scholars have consistently emphasized that overcoming fragmentation requires fostering open collaboration, deliberate knowledge-sharing, and organizational culture alignment [13,23,33]. Without these elements, fragmentation can undermine project performance [14]. Poor coordination and inadequate communication lead to inefficiencies such as rework, uncertainty, and heightened complexity, factors that collectively extend project duration and intensify fragmentation [17,26,34].

In the AEC industry, fragmentation can occur both vertically among participants operating in different phases of the project (e.g., designers and contractors) and horizontally among participants within the same phase (e.g., different design specialists) [35]. To address these challenges, the AEC industry has increasingly turned to integration as a strategy to enhance the efficiency and quality of production processes [36–40].

Baiden and Price [16] define integration as a condition where different disciplines or organizations with different goals, needs, and cultures merge into a single cohesive and mutually supporting unit with a collaborative alignment of processes and cultures.

Koolwijk et al. [40] determined four components of collaboration and integration in the construction industry: (1) information sharing deals with the sharing of information among the members and the use of information technology to exchange and manage information; (2) inclusive decision making refers to the level of involvement of top and

middle management in the project and joint decision making by the client and suppliers; (3) collaboration concerns the interpersonal processes and reflects the level of trust and commitment between people and also the sense of belonging to a team in the supply chain; and (4) financial integration involves the sharing of risks, costs, and rewards along the chain and sharing of sensitive financial information to evaluate the financial performance of the single entities in the supply chain.

2.2. Organization: Differentiation, Integration, and Fragmentation

Lawrence and Lorsch [41] define an organization as a system of interrelated behaviors of people performing a task. In this system, people process information and communicate along specific lines of communication (e.g., formal lines of authority) via communication tools (e.g., memos, voice mail, and meetings) to achieve a specific set of tasks with limited capacity [42].

The organizational system is differentiated into several distinct subsystems that develop a portion of the task. Then, there is a process of integration to achieve unity of effort among the subsystems to accomplish the organization's tasks [41]. However, fragmentation can occur in this process, which differs from differentiation. Fragmentation goes beyond segmentation, including poor coordination, collaboration, integration, and communication [24,37,43].

The AEC industry is fragmented compared to other industries because its work is separated between different stakeholders and different subprocesses [44]. The high fragmentation and project-based nature of the industry pose a significant challenge to the inter-organization or intra-organization integration of the AEC industry [45].

Inter-organization integration refers to the teamwork of the project team, which comprises representatives from the owner, designer, and contractor organizations involved in producing the results to achieve a project's effectiveness. Meanwhile, intra-organization integration refers to the teamwork of the project teams of members from one organization that focus directly on enhancing one organization's effectiveness and indirectly on contributing to a project's effectiveness [46,47].

Inter-organization integration has attracted considerable attention in the AEC industry over the years and has been studied [47–49]. However, intra-organization integration has been studied less, especially in industrialized companies in the AEC industry. This paper focuses on intra-organization integration, especially the impact of organization and process fragmentation and integration on project performance.

2.3. Virtual Design Team

The Virtual Design Team (VDT) emerged in the late 1980s as a research initiative to create a computational method to model and simulate project organizations conceived as information processing structures [17,50–53]. According to Yin and Levitt [31], from this perspective, organizations can be understood as systems designed to process information and facilitate communication to complete defined tasks. These systems comprise individuals or teams with limited processing capacity and constrained rationality. Information is exchanged through designated communication channels—often aligned with formal authority structures—and transmitted using tools with capacity limitations, such as emails, meetings, or written memos.

By modeling tasks, organizations, and communication flows, VDT accounts for the complexities of project workflows, predicting direct work, rework, coordination demands, and decision wait times [17,50]. SimVision was developed as a software tool derived from the VDT theory to develop and run simulation models.

SimVision enables precise modeling and forecasting of project completion times, potential risks, resource workloads, and quality performance by combining organizational and process-based perspectives [54]. Simulating different project scenarios facilitates a comparative analysis against a chosen baseline, thereby revealing optimization opportunities in project structures [54].

SimVision's modeling framework can be divided into two key components: inputs and outputs. Inputs constitute the data and parameters needed to configure the simulation, such as descriptions of tasks, organizational roles, and process flows, while outputs are the simulation's results, including predictive metrics and specialized charts that illuminate schedules, workloads, risks, and other performance indicators.

3. Methodology

As a consequence of the nature of this research, which seeks to study the organization's interaction and processes of an industrialized company, this research uses simulation modeling because of the challenges of performing actual experiments on the company. Due to the research's characteristics and variables under analysis, the authors chose the VDT model as an appropriate methodology for analysis. The VDT model is a unique tool that provides appropriate modeling elements to model project organizational and process performance [17]. The simulation framework of the VDT model has been developed and validated over the past 25 years to help project managers design organizations and processes [17,50,53–59]. Because VDT requires high data transparency to capture realistic project conditions, projects with repetitive processes and controlled environments—such as industrialized construction—are particularly well-suited to modeling with VDT [52].

The methodology process for building the VDT model comprises the following steps (Figure 1).

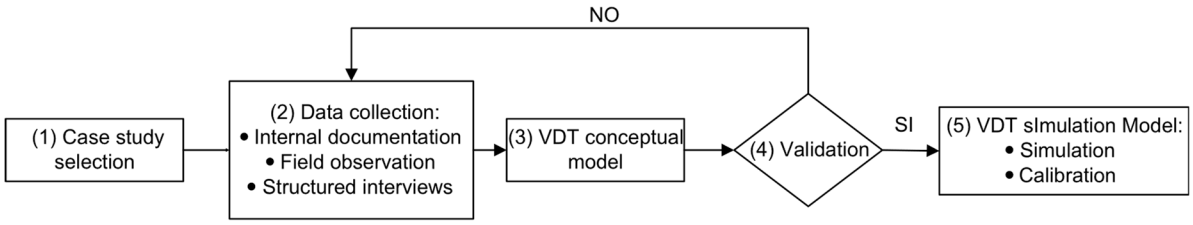


Figure 1. Research methodology (adapted from Mesa et al. [17]).

3.1. Case Study Selection

The first step involves introducing the industrialized company and the modular construction project that serves as a reference point for creating the VDT simulation model, named baseline.

As a case study, this research used an industrialized timber building company in Chile dedicated to manufacturing modular units, from conceptual design to final delivery to clients. The company's primary production process takes place in a manufacturing plant. Within this worksite, the company develops four key activities: rough work (involving the manufacture of panels for walls, floor, and ceiling, which are later assembled to form the module), plumbing installations (handled by a specialist plumbing subcontractor), electrical installations (handled by a specialist electrical subcontractor) and finishing (handled by a specialist finishing subcontractor).

The authors chose this modular company because it complies with the definition provided for industrialized construction, which is that a modular unit is produced and preassembled in off-site manufacturing plants and incorporates finishes, electrical, plumbing, and even furniture fixtures [5]. Once on the site, these units are assembled to form

a building [9]. Additionally, the authors had access to all information about the company's organization and processes, enabling the collection of optimal data input necessary for SimVision.

The authors used a standard model of a modular office project to create the simulation model in SimVision, considering the same standard components and processes, making it extrapolated to an actual company project. The "Modular Office Complex" consists of five modules measuring fifty square meters. The project yields a total area of 250 square meters. The project merges meeting rooms, personal offices, and restrooms.

3.2. Data Collection

The authors compiled data through internal documentation, structured interviews, observation, and measurement of the on-site construction processes and the organization of the company's manufacturing plant. Also, the second author's professional experience in the company complemented and strengthened the data collection with their knowledge about the company's organization and processes.

Internal documentation was collected directly from the case company. The dataset included various formal project information: production schedules, project charters, design deliverables, and meeting records. These documents were selected in collaboration with company professionals, who identified information relevant to understanding the project's organizational structure, task sequences, and decision-making flow.

Each document was systematically reviewed to extract information on the project timeline, key milestones, role assignments, and the sequencing of activities across the design and manufacturing phases. Production schedules were analyzed to determine task duration, start–end dates, and dependencies. Project charters and design deliverables were used to identify stakeholders' responsibilities and deliverable handoffs. Meeting records were especially valuable in revealing coordination issues, communications pathways, and decision logics not visible in formal plans.

The extracted information was organized into matrices linking tasks, roles, and communication flows, which were used to support the empirical case description and the parameterization of the VDT simulation model.

The second author conducted field observations through a comprehensive walkthrough of the production facility. In this walkthrough, the author recorded detailed field notes about the physical setup of modular assembly stations, the flow of materials and information between work areas, and any observed coordination challenges between manufacturing and site teams. These observations offered firsthand insights into bottlenecks, scheduling constraints, or task overlaps that might not be apparent in official documentation.

The authors used structured interviews to gather consistent information on each participant's responsibilities, communication channels, and typical decision-making procedures. The authors developed an interview guide in advance to ensure comparability across responses. It was organized into three thematic sections: (1) task assignments, (2) communications channels, and (3) decision-making roles and coordination mechanisms. The questions were tailored to align with the data requirements of the VDT modeling approach.

The interviews were conducted on-site at the company's offices and lasted 90 min each. Three key professionals were selected based on their central roles across the design, procurement, and production stages: the architect, purchase planner, and process engineer online. Each interview was conducted individually in a private setting, allowing for open and uninterrupted discussion. The second author encouraged participants to refer to

real project documents and workflows, which helped validate responses and clarify the information that was collected in the field observations.

The data were then organized into structured tables identifying the relationships between organizational roles, task sequences, communication links, and coordination challenges. These structured insights were used to define the VDT model parameters and were cross-validated with field observations and internal project documentation, reinforcing the model's empirical grounding.

Finally, the authors joined and compared the internal documentation, on-site observations, and interviews to ensure accuracy and consistency in modeling the real-world project environment. This process involved systematically comparing information across sources to validate key aspects of the project's organizational structure, workflows, and stakeholder interactions.

The internal documentation provided formal task sequences, role descriptions, and scheduled milestones. These were cross-referenced with field notes from on-site observations, which captured actual coordination dynamics, task execution practices, and informal interactions not reflected in official documents. Interviews were then used to confirm these findings, offering detailed explanations of decision-making procedures, communications bottlenecks, and stakeholder responsibilities from the perspective of professionals directly involved in the project.

Converging information across all three sources was used to define the parameters of the VDT model, including task duration, role assignment, communication, and coordination. This triangulation ensured that the simulation closely mirrored the project's actual conditions, increasing the model's empirical validity and relevance for analyzing fragmentation and integration scenarios.

3.3. Development and Validation of the VDT Conceptual Model

The VDT model represents the current scenario of the company's organization and the processes used to develop a modular project. Based on the collected information, the authors work individually to create the VDT model using SimVision's graphical representation. Once the author had this representation of the organization and processes, the authors setup another interview with the key participants to validate the VDT model. The interview aimed to determine if the model is requisite [60]. That is, determine if the model captured the underlying features and characteristics of the company's organization and processes [17]. The authors implement the following steps suggested by Mesa et al. [17] to apply this interview:

- Step 1: Explanation of the VDT conceptual model: The authors first introduce the meaning of each shape and link of the VDT model that represents the organization and processes. Then, the authors explained the composition of the company organization, links among project participants or groups, the type of meetings, links between participants and processes, the sequence of the processes, and links among processes.
- Step 2: Comparison between the VDT conceptual model and the actual project events: After familiarizing themselves with the VDT conceptual model in Step 1, the key participants compared real-world organizations and processes to the model's graphical representation. They confirmed or corrected aspects such as the organizational structure, participant relationships, activity links, and process sequencing in an open discussion.

3.4. Simulations

This final step consisted of simulating and calibrating the simulation results. The authors used SimVision to run the VDT models. SimVision provides a graphical and

menu-driven user interface that allows users to define project tasks, organizational roles, communications links, and their interdependencies. The simulation process begins by entering task attributes (e.g., duration, complexity, and uniqueness), assigning roles to each task, and establishing links among tasks (e.g., successor, communication, or rework dependencies). Organizational roles are defined and connected to each other via supervisory links. Once the VDT conceptual model is complete, key behavioral parameters, such as decision-making levels, cross-functional team levels, and task communication, are configured using SimVisions's parameter editor.

The calibration process sought to illustrate a possible scenario for a company's modular project in terms of project duration and types of work (direct work, rework, coordination, and waiting volume). The calibration process comprised the definition of the VDT's property values (Table 1) to obtain the CPM duration (planned) that represents the duration of the company's standard project. The VDT's property values were defined based on the information collected in the company's plant (Section 3.2), the experience and knowledge of the key participants, the authors, and the user guide of the software SimVision.

Table 1. Properties of the VDT model to simulate organization and process characteristics—baseline.

Property	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6
Priority	Medium	Medium	High	High	High	Medium
Team continuity	High	High	High	High	High	High
Decision level	Medium	Medium	Medium	Medium	Medium	Medium
Meeting preferences	Medium	Medium	Medium	Medium	Medium	Medium
Cross-functional team	Low	Low	Low	Low	Low	Low
Task communication	0.2	0.4	0.4	0.6	0.6	0.5
Distraction level	0.25	0.25	0.25	0.25	0.25	0.25
Work complexity	0.1	0.1	0.1	0.1	0.1	0.05
Project uniqueness	0.1	0.1	0.1	0.1	0.1	0.5

After the VDT conceptual setup, the simulation engine processes this data using embedded behavior algorithms derived from the VDT theory. The default number of trials in SimVision is 25. The user guide of the software SimVision recommends more than 10 trials to increase the stability of predicted results and reduce the standard deviation. SimVison calculates performance metrics such as predicted project duration, volume of direct and indirect work (rework, coordination, and waiting), and risk of schedule growth. These outcomes are presented through visual dashboards, time series charts, and detailed tables. For this study, interpretation focused on comparing baseline and integrated scenarios, identifying phases and roles with high rework or coordination load, and quantifying the impact of integration strategies on project performance. This approach enables replicability and facilitates a structured analysis of how organizational and process factors drive project outcomes.

4. Results

This section presents a description of the results of the VDT model. The authors divided the results into the VDT conceptual and simulating models to facilitate comprehension. The VDT conceptual model section explains the organization and processes of the industrialized timber building company in producing a modular office project. The VDT conceptual model was obtained from the collected information using SimVision's graphical representation. Then, the VDT model simulation section introduces the properties and

their results regarding project duration, schedule growth risk, and work volume. The VDT conceptual model was simulated using the computer software SimVision to obtain the simulation results.

4.1. Description of VDT Conceptual Model

Figure 2 shows the VDT conceptual model of the baseline case. The VDT model is read from top to bottom and left to right. The project organization is at the top (green people icons), and the project process is at the bottom (yellow and turquoise forms). The project organization is divided into four project teams (a) modular factory, (b) electrical, (c) plumbing, and (d) finishing subcontracts. The modular company, which is formed by the company's professionals, is structured into functional departments: commercial, planning, engineering, supply chain, and production. The electrical (a), plumbing (b), and finishing (c) subcontractors are involved in the manufacturing process (rough work and finishing phases) and organized by a linear structure. The project process comprises two milestones (new project and finish) and six phases divided into two groups (yellow forms): design phases (sales takeoff, project detailed design, and project startup) and manufacturing phases (rough work, finishing, and final reception), and two milestones (new project and finish). The phases are connected by successor relationships (black arrow) and orange links that show the connection among tasks of the phases.

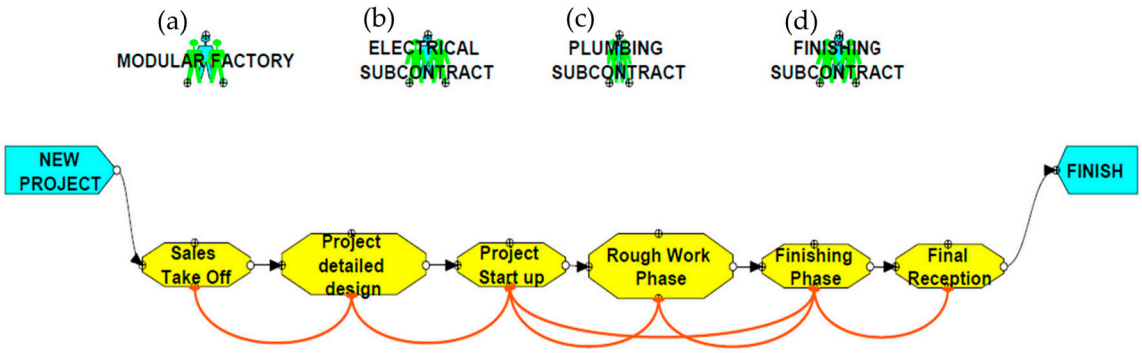


Figure 2. The VDT conceptual model.

Inside the VDT model, each phase has its own organization and process. The VDT model's symbols and links are interpreted as follows: The project organization is defined by the relationship between positions that participate in the development of processes. These positions are linked to each other with supervision links (black line). This link defines which position (group or individual) would go for information or to report an exception (e.g., design change, error detected) [17]. Positions are also linked to processes with blue assignment links, which means which position is responsible for which task.

The project process comprises tasks and milestones. Tasks are linked by a successor and work reciprocal or reciprocal information dependency [61,62]. Work reciprocal relationship (rework link (red dashed line)) describes corrective iteration that responds to issues arising later in the life cycle or to correct errors introduced earlier or to implement a change [63]; that is, corrective iteration is a rework that occurs when an exception in one task (the driver task) requires work already completed on another task (the dependent task) to be redone. The driver task is usually upstream or roughly parallel with the dependent task in the chain of task precedence [54]. A reciprocal information relationship (communication link) represents a mutual information requirement dependency between two activities (green dashed line) when an exception, coordination, or rework occurs [17,54]. The VDT conceptual model of the six phases is explained as follows:

(a) Phase 1: Sales Takeoff (Figure 3): The project process starts with the commercial process in the Sales Takeoff phase (a). The client defines its project requirements with the sales executive during this process. Then, the architect and project planner work separately on conceptual design and preliminary technical specifications. This phase ends when the client approves the preliminary design. In this phase, it is highlighted that the client's approval of the preliminary design negatively impacts scope definition and conceptual design tasks due to the corrective iterations generated during this phase.

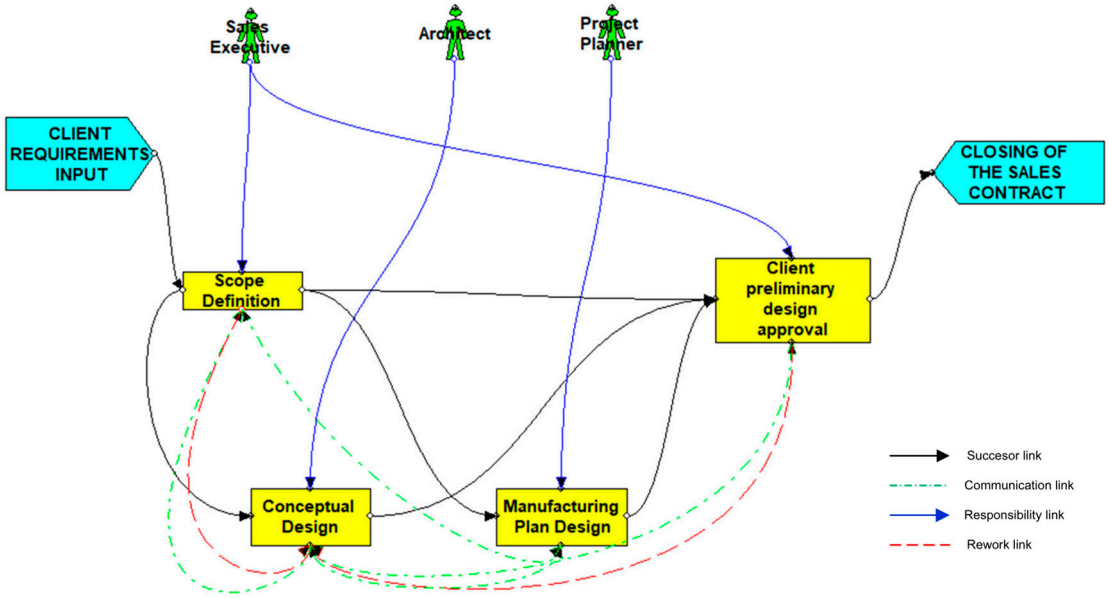


Figure 3. VDT conceptual model of Phase 1—Sales Takeoff.

(b) Phase 2: Project Detailed Design (Figure 4): Once the client approves the conceptual design, the material takeoff supervisor, architect, electrical designer, and plumbing designer start with the detailed design, where each specialty works separately. This phase comprises the following tasks: material takeoff, electrical plans, sanitary plans, and architectural plans. The architectural plans task is connected with the material takeoff task with a rework and communication link. The final product of this phase is the detailed design.

(c) Phase 3: Project Startup (Figure 5): Then, in the project startup, the participants prepare the final plans (architectural, electrical, and sanitary), which are submitted for the client's approval and subsequently released as "approved plans for construction." To accomplish this project goal, the sales executive, architect, material takeoff supervisor, purchase planner, warehouse attendant, and production assistant manager participate in the "project meeting." In this meeting, they make decisions and define the approved plans for construction. The manufacturing day setting task is connected with rework links to all other tasks in this phase. This task is also connected with communication links with tasks from Phase 2 (gray rectangles). All tasks are connected with rework links to tasks from Phase 2. In this phase, the purchase planner works on the tasks of purchasing manufacturing materials and their delivery to the factory.

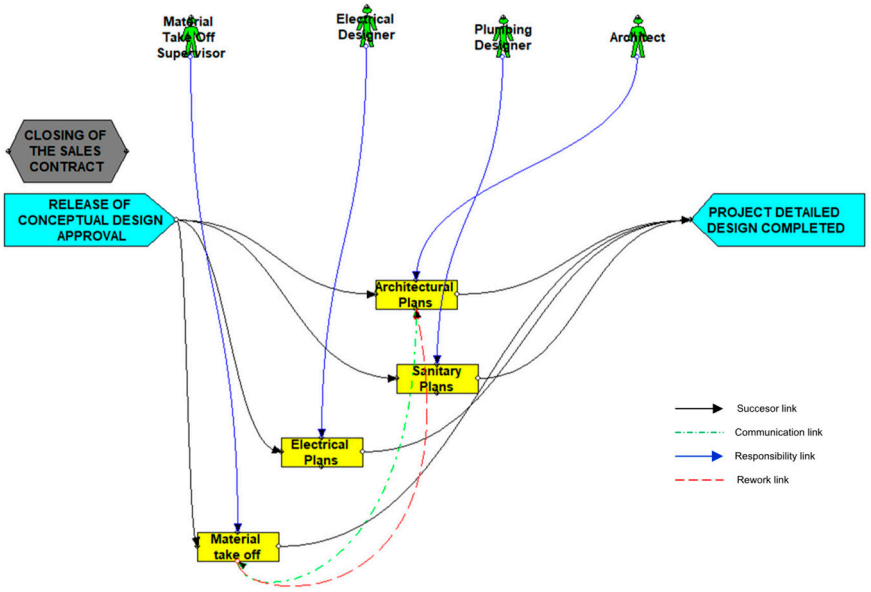


Figure 4. VDT conceptual model of Phase 2—project detailed design.

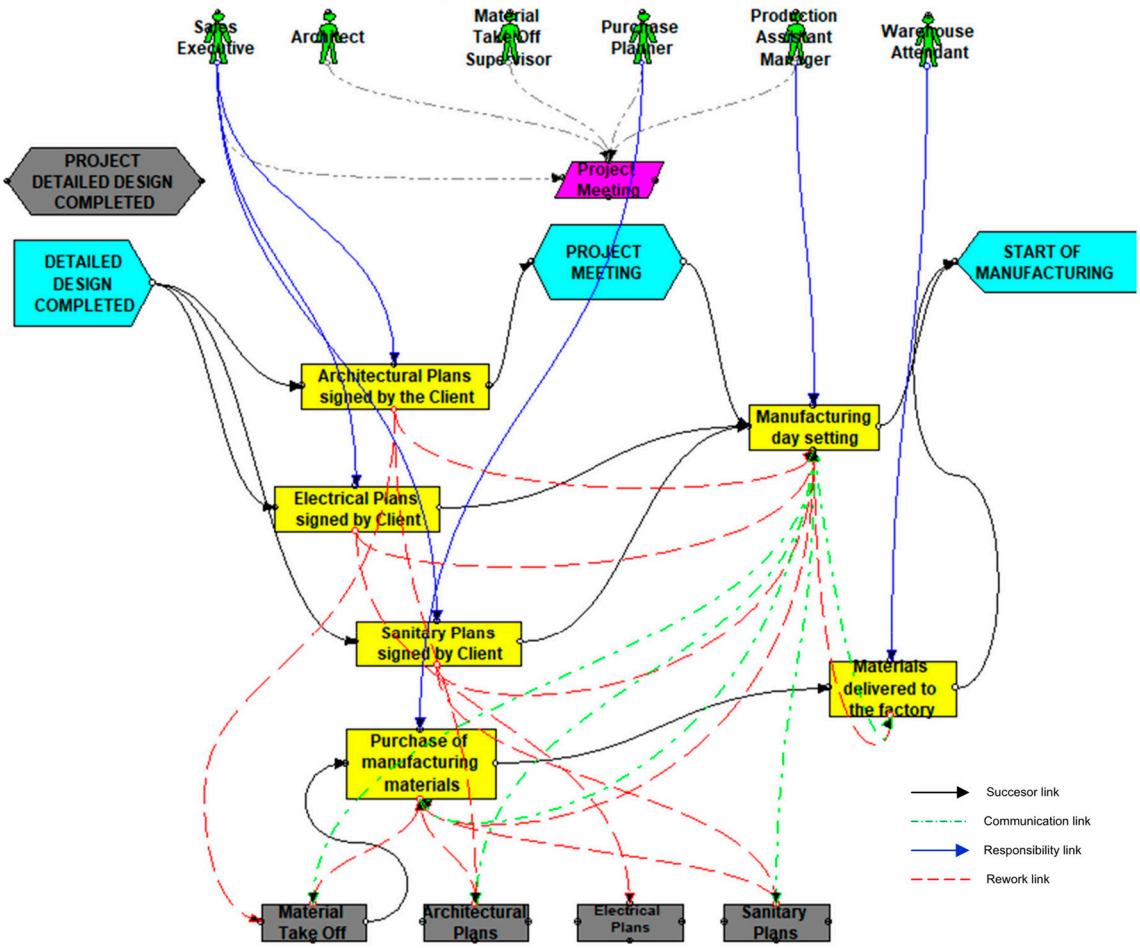


Figure 5. VDT conceptual model of Phase 3—Project startup.

(d) Phase 4: Rough Work (Figure 6): Based on these approved plans, the production assistant manager coordinates with wood, framework, electrical, and plumbing supervisors on the rough work phase. The process focuses on the fabrication of modules. This phase comprises four main milestones: framework, electrical pipes, plumbing, and rough work. All framework, electrical, and plumbing-related tasks are connected

with rework links, including architectural and electrical plans signed by the client from Phase 3 (gray rectangles). The communication links are only present at the level of supervision tasks.

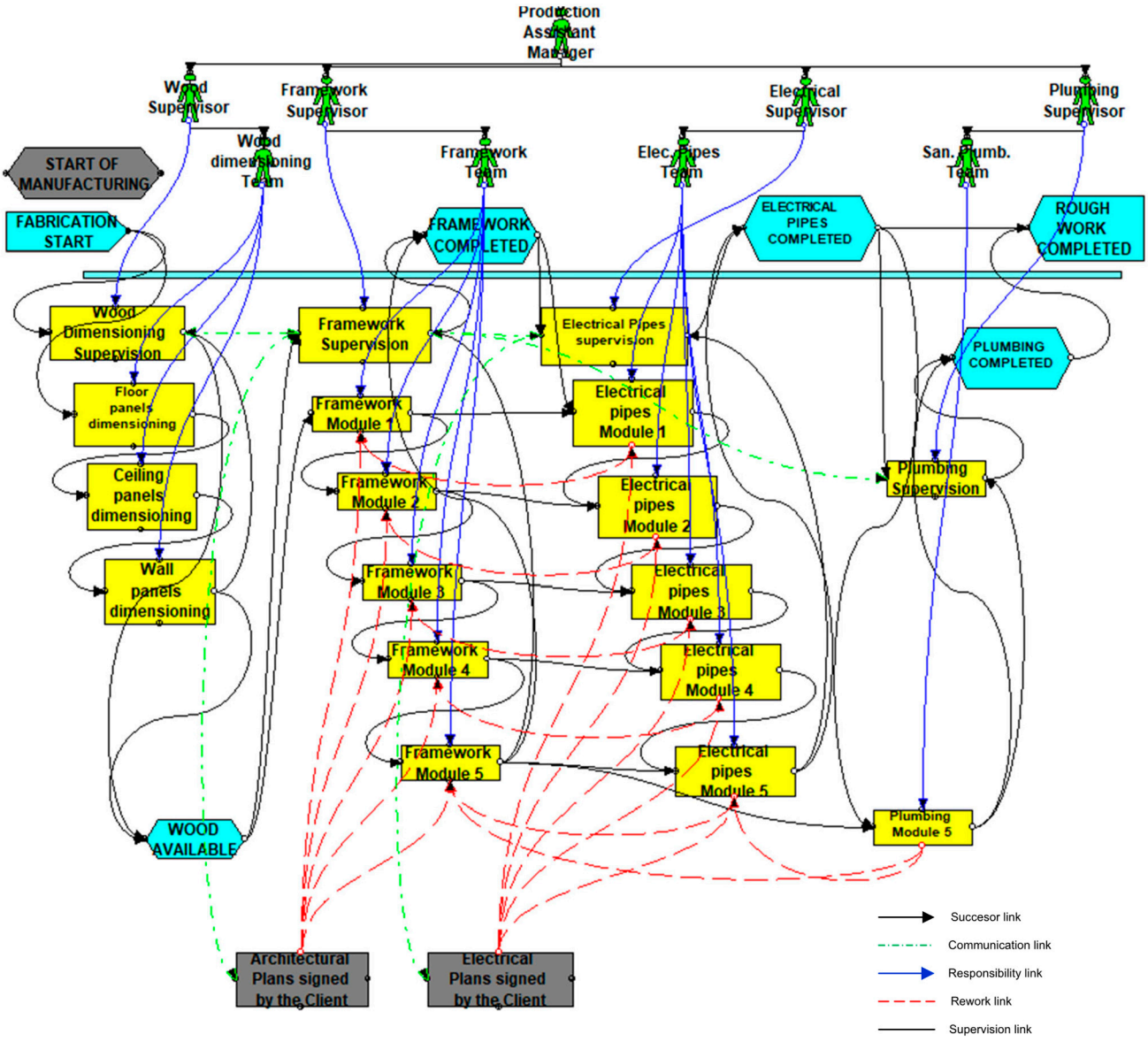


Figure 6. VDT conceptual model of Phase 4—rough work.

(e) Phase 5: Finishing (Figure 7): The process focuses on installing electrical and sanitary appliances and finishing, and ends with the quality approval task. The production assistant manager coordinates with electrical, plumbing, and finishing supervisors on the finishing phase. This phase has four main milestones: electrical, sanitary, fabrication, and quality control. All electrical tasks are connected to electrical tasks from Phase 4 (gray rectangles), and electrical plans signed by the client from Phase 3 (gray rectangles) with rework links. Finishing tasks are also connected to architectural plans signed by the client from Phase 3, with rework links. The quality approval task is connected to electrical and finishing tasks using rework links. The communication links are only present at the level of supervision tasks. The final product of this phase is the fabrication.

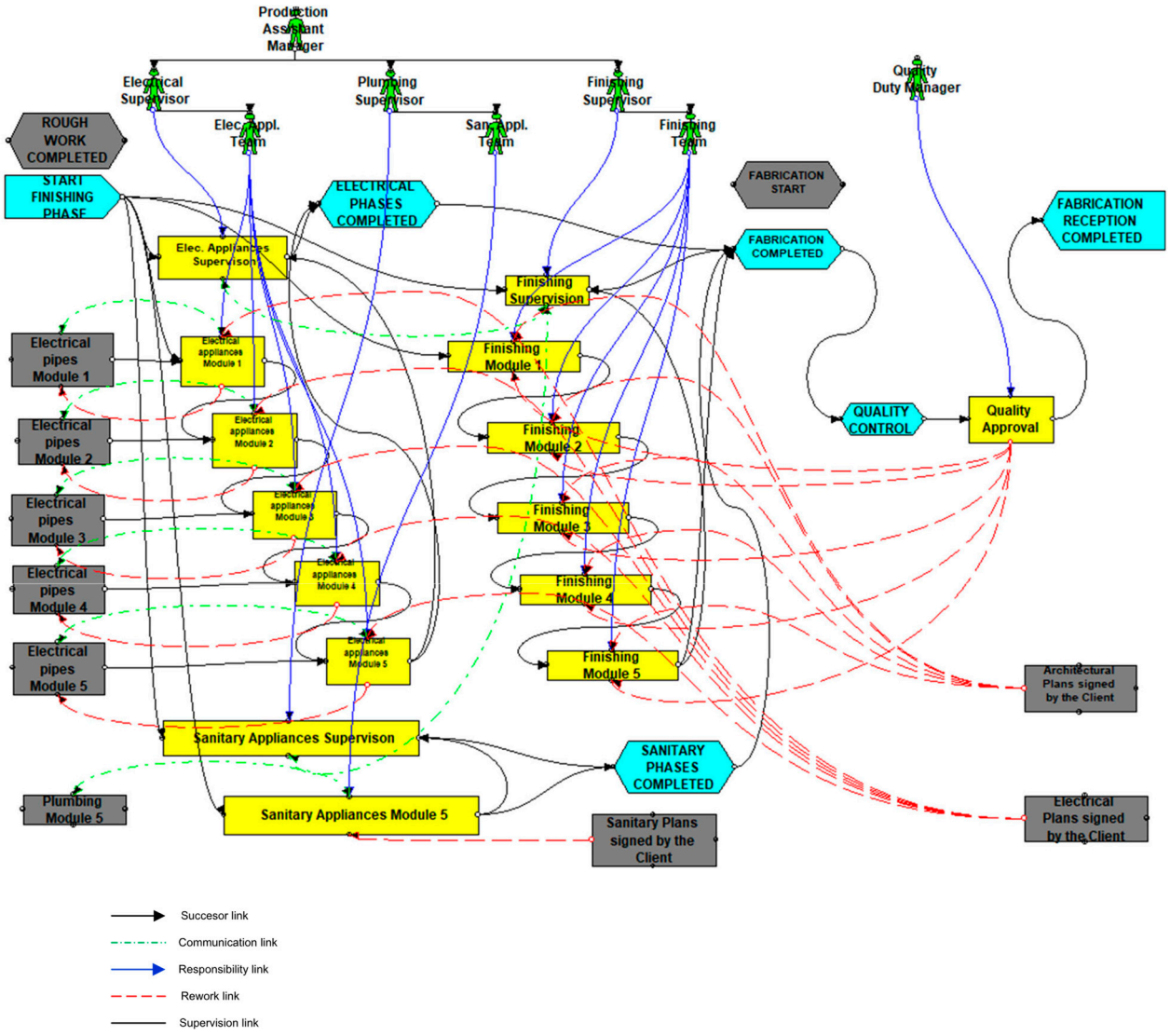


Figure 7. VDT conceptual model of Phase 5—finishing.

(f) Phase 6: Final Reception (Figure 8): The logistic attendant is responsible for delivering the modules to the client when the manufacturing processes are completed. This phase is closed with the client's final reception.

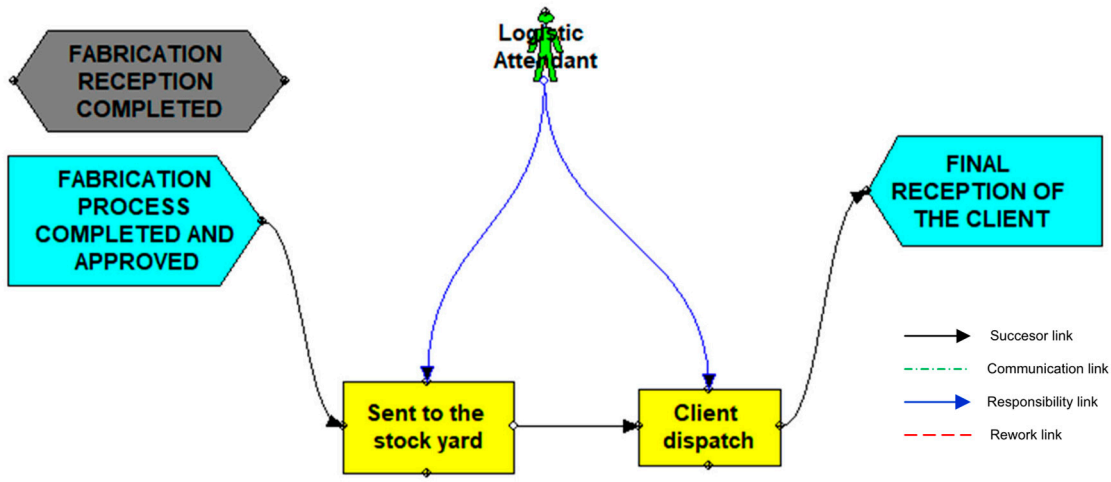


Figure 8. VDT conceptual model of Phase 6—final reception.

Based on the description of the phase's VDT conceptual model, fragmentation occurs in the company's organization and process due to the separation of the design from the manufacturing process and poor communication and coordination between and within phases. The organization is differentiated into functional departments, but there is fragmentation between the manufacturing process and the definition and design phases. That is, the subcontractors of the rough work and finishing projects do not participate in the project's early stages and work together with the design specialties. Additionally, each specialty works separately within each phase. For example, in the detailed design phase, there is fragmentation of expertise, situated knowledge, and poor coordination among specialties to work together efficiently.

4.2. Description of VDT Simulation Model

This section explains the VDT's properties to simulate the interaction between the project organization and processes to build the modular office. The computer software SimVision requires some organization- and process-based inputs to run the simulation. For this study, the authors considered the following main inputs [54]:

- Project priority indicates how important this phase is to the overall project (high—medium—low).
- Team continuity measures how successfully the team has performed related projects (high—medium—low).
- Decision level indicates the qualitative degree to which decision-making and exception-handling responsibilities are decentralized to individual responsible positions (low) or centralized to senior project managers (high). If the decision level is low, rework decisions can be evaluated by the responsible positions. If the decision level is higher, the decision is more likely to be escalated to a supervisor somewhere in the hierarchy—a subteam leader if the decision level is medium.
- Meeting preference measures how formal the communication is in an organization. High meeting preference means communication tends to occur in formal meetings.
- Cross-function team measures the extent to which positions are located in skill-based functional departments and supervised directly by functional managers (low) or co-located with other skill specialists in dedicated project teams and have project supervision from a project manager (high).
- Task communication measures the level of communication in the project between positions responsible for tasks linked by communications (green) links (0.0 to 1.0).
- Distraction level measures the "effect of interruptions in the ordinary working day that take time away from performing the project tasks." (0.0 to 1.0).
- Work complexity is the probability that a task will fail and require rework (0.0 to 1.0).
- Project uniqueness is the probability that a task will fail and generate rework for itself and all dependent tasks connected to it by rework links (0.0 to 1.0).

Table 1 presents the properties of the six phases. The properties' values were defined based on the information collected from internal documentation, field observation, and interviews, following the recommendations and instructions of the user guide of the software SimVision, especially to assign the values of task communication, distraction level, work complexity, and project uniqueness.

According to these properties, the company organization is characterized by having a low level of cross-function team; that is, people in the organization are located in skill-based functional departments and supervised directly by functional managers. The organization's decision level is medium, which means decisions are more likely to be escalated to a subteam leader. The level of task communication among specialties within each phase varies from low in the early phases to medium in the downstream phases. The communication

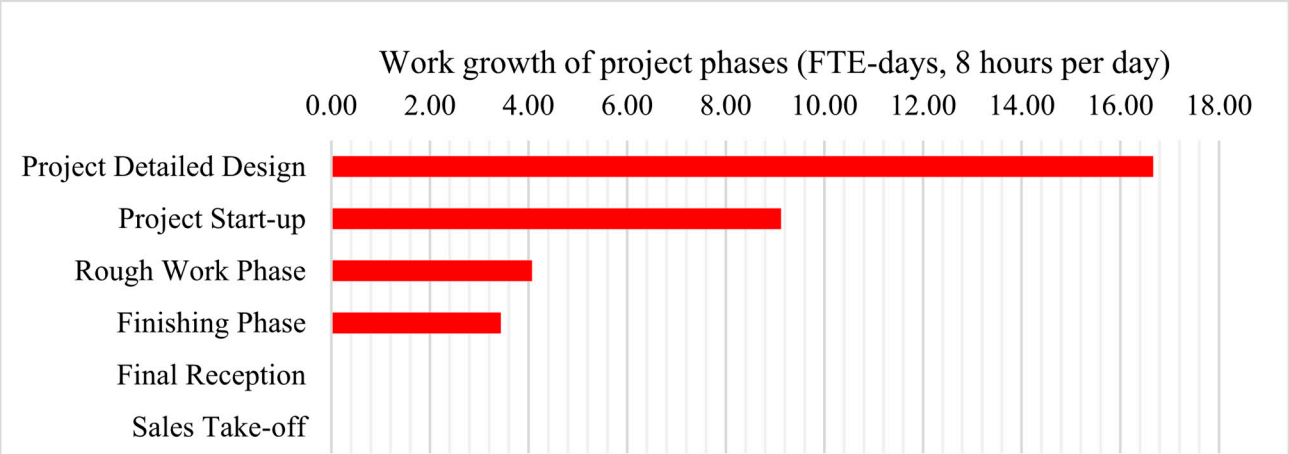
among specialties between each phase is low, especially between the manufacturing and the definition and design phases.

4.3. VDT Simulation Results

4.3.1. Project Duration and Schedule Growth

The simulation results show that the simulated duration for the modular office's definition, design, fabrication, and final reception is 102 days (+/− 0.21 days) compared to the CPM duration (planned) of 69.6 days. This means the project has a scheduled growth of 34 days. The CPM duration reflects an optimistic scenario where all positions are fully available to work all the time on all their tasks and ignore communications between positions about tasks, exceptions in tasks, and the resulting rework and possible backlog for the responsible positions [54]. Meanwhile, the simulated duration considers all these factors to reflect the real-world model in the VDT conceptual model.

The authors make a detailed analysis in SimVision to understand which phases have the highest incidence in the simulated duration; that is, it has a significant schedule growth risk larger than 4 days. According to the simulation results (Figure 9), the phases with significant schedule growth risk are project detailed design (9.12 days) and project startup (16.6 days). Then, the detailed analysis of the scheduled growth risk of the project's detailed design reveals that the architectural plans have the greatest growth risk. Meanwhile, in project startup, the purchase of manufacturing materials has the highest growth risk.



	Sales Take-off	Final Reception	Finishing Phase	Rough Work Phase	Project Start-up	Project Detailed Design
Critical path	0.00	0.00	3.44	4.07	9.12	16.67

Figure 9. Project schedule growth chart of the project phases.

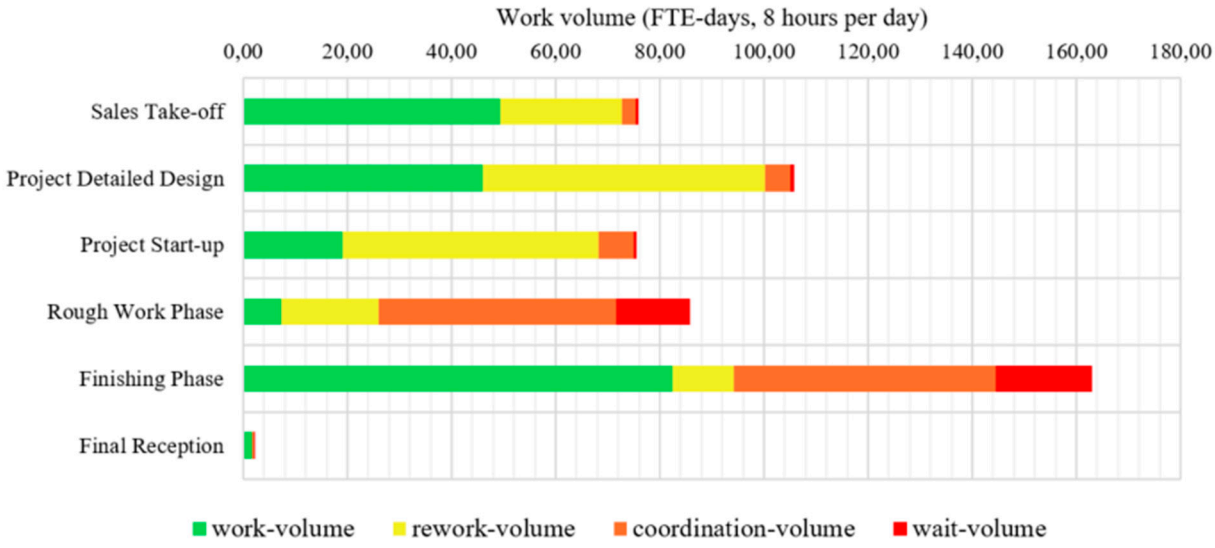
4.3.2. Project Work Volume

SimVision reports the work volume in direct work, rework, coordination, and wait volume. According to the user guide of the software SimVision, these types of work volumes are defined as follows [53]:

- Direct work volume is the predicted time that all positions on a project spend performing the original work that a task requires before any exceptions are handled.
- Rework volume refers to the predicted time needed for all positions on a project to do work that has to be redone on a task due to exceptions.

- Coordination volume is the predicted time during a project or program that all positions spend at meetings and processing information requests from other positions.
- Wait volume is the cumulative time spent by positions waiting for decisions to be made in a project.

Regarding the work volume (Figure 10), the sales takeoff (49.4), finishing phases (82.4), and project detailed design (46) are the phases with the longer direct work volume, followed by project startup (19.1), rough work (7.26), and final reception (1.7). On the other hand, the rough work (91.54%), project startup (74.7%), project detailed design (56.53%), and finishing phase (49.48%) have the highest percentage of indirect work (rework, coordination, wait volume). The rework volume has a higher incidence in the indirect work of project startup and project detailed design (54.1 and 49.19, respectively). Meanwhile, the coordination and wait volume have more incidence in the rough work (45.72 and 14.21, respectively) and finishing phases (50.23 and 18.57, respectively).



Project	Direct Work	Indirect Work			Total Work Volume	Direct Work (%)	Indirect Work (%)
		Rework	Coordination	Decision wait			
Sales Take-off	49.40	23.35	2.61	0.52	75.88	65.10%	34.90%
Project Detailed Design	46.00	54.10	4.92	0.80	105.82	43.47%	56.53%
Project Start-up	19.10	49.19	6.70	0.50	75.49	25.30%	74.70%
Rough Work Phase	7.26	18.67	45.72	14.21	85.86	8.46%	91.54%
Finishing Phase	82.40	11.89	50.23	18.57	163.09	50.52%	49.48%
Final Reception	1.70	0.3	0.33	0.11	2.44	69.67%	30.33%

Figure 10. Project Work Breakdown.

The rework and coordination volume results reflect the horizontal and vertical fragmentation in the company's organization and process. As explained, the company organization is structured in skill-based functional departments with inefficient communication and low cross-functional levels among specialties within and between phases.

The horizontal fragmentation is explained by inefficient communication among specialties within the design phases (sales takeoff, project detailed design, and project startup). Low cross-functional levels explain the vertical fragmentation, that is, the fragmentation

between the manufacturing phases (rough work and finishing phases) and the definition and design phases (sales takeoff, project startup, and project detailed design).

This poor teamwork and communication affect the design, and errors or changes are only detected during the manufacturing process. Therefore, in the manufacturing phases, corrective iterations occur due to exceptions or adverse events (errors or changes in the design) that require work already completed to be redone in the definition and design phases. Hence, participants (positions) in the rough work and finishing phases had to coordinate these exceptions following the decision level, which, in this scenario, is medium. That means the responsible positions escalated the decision to a subteam leader of the rough work and finishing phases. Then, subteam leaders must communicate with the responsible positions of project startup and project detailed design to inform them about these exceptions and request that they address them, which requires redoing design work already completed. This explains the high volume of rework in the project's detailed design and project startup phases and the high volume of coordination in the rough work and finishing phases to solve these corrective iterations.

5. Discussion of VDT Simulation Results

The results of the VDT conceptual model show that the project teams involved throughout the six phases work in isolation. There is fragmentation between manufacturing (rough work and finishing) and design phases (sales takeoff, project detailed design, and project startup), even though they belong to the same company that provides all services (e.g., definition, design, and manufacturing).

The organizational structure is functional (hierarchical). It is divided into departments for each specialty: commercial, planning, engineering, supply, and production. Each department is physically located in the same place, but works independently in separate offices. The coordination occurs through e-mails and shared information on the company's servers. This type of organizational structure, with specialized individuals working in silos with minimum coordination, contributes to fragmentation [24,32].

The VDT simulation results reveal that fragmentation in the early phases of the project leads to exceptions or adverse events (errors or changes in the design) that are not detected in time in the design phases and appear in the manufacturing phases, which results in a high level of coordination and wait work volume in the rough work and finishing phases. Then, the design specialties must address these errors and changes in the design, which generate a high level of rework volume in the detailed design and startup phases.

As an early integration opportunity, a coordination meeting is held in the project startup, where all the areas involved in the modular factory analyze the general aspects of the project, especially quality requirements and the delivery date to the client. However, this meeting occurs very close to the start of manufacturing, which does not facilitate adequate response times to any problems detected in the project specifications and drawings. Additionally, the subcontractors do not participate in this meeting to incorporate their experience and knowledge of the rough work phase into the project's detailed design. This separation hinders design and manufacturing knowledge integration and diminishes the opportunity for manufacturing specialties to influence design decisions.

According to the time measurements of the work volume, the fragmentation of the organization and processes through the six projects negatively impacts the project performance, considering that the project was delayed by approximately one month. This delay is mainly due to the long rework times that occur primarily in the detailed design and project startup phases, and the waiting times for decision making to solve a requirement in the rough work and finishing phases.

These rework and waiting times for decision-making are generated because some tasks in the definition and design stage are not entirely finished; for example, sometimes, the project team incorporates changes in the project designs that were accepted while the manufacturing process is already underway. These changes generate redesigns, impacting design task times and, especially in manufacturing, generating work overloads. This is reflected in the sensitivity analysis of the simulation model, which shows that the project's detailed design and project startup significantly impact the project's final performance.

Based on these results, the VDT simulation model allowed observing the importance of generating vertical and horizontal integration of the project team, especially early integration in the design stages of the project, since this is the moment when there is the greatest capacity to influence the functional aspects of the project at a lower cost. These findings offer an important practical takeaway in the sense that the early phases of the project (e.g., detailed design and project startup) are critical for improving project performance through integration. The simulation results show that fragmentation during these early phases leads to a cascade of rework and delays downstream, particularly during manufacturing. Therefore, project managers should prioritize stakeholder integration during the design definition phase, when coordination across departments and early input from manufacturing teams can prevent design inconsistencies and reduce rework. Implementing structured collaboration mechanisms, such as the co-location of multidisciplinary teams, early-stage project review meetings, and decentralized decision-making protocols, can significantly enhance responsiveness, reduce exception handling times, and avoid late-stage disruptions. Recognizing and acting during early phases can yield large benefits for project performance.

Sensitivity Analysis

Using the VDT simulation model, the authors conducted a sensitivity analysis to study how integration impacts project performance. For this purpose, the authors modified the organization and two properties, the cross-functional team and the decision level, and fixed the other properties, creating the VDT's version 2. These changes in the VDT model focus on simulating the effect of incorporating the manufacturing specialties in the design phase and encourage the co-location of the project team.

We modified the organization of the sales takeoff (Figure 11) and project detailed design phases (Figure 12) to encourage horizontal integration. For that purpose, the sales executive takes the project manager role and coordinates the architect and electrical and plumbing designers in these phases. This configuration in the organization seeks that these specialties in these phases work together as an interdisciplinary group that shares information and knowledge under the project manager's leadership to facilitate the collaborative design of the project.

The authors also modified the organization in the project startup phase to encourage vertical integration (Figure 13). In this case, the authors integrated the electrical supervisor, plumbing supervisor, quality manager, and logistics attendant in the Project Startup phase to work collaboratively with the design specialists. This way, all design and manufacturing specialties participate in the project meeting to share information and knowledge to reduce exceptions (design errors or changes) that affect the downstream tasks.

Based on the changes in the organization that seek to integrate different specialties within and between phases, the author increases the level of cross-function team to medium to model that specialists are co-located with other skill specialists and work together in the same office to maximize collaboration, as well as to facilitate informal and formal interaction and share of information and knowledge to eliminate corrective iteration. Additionally, the author reduces the decision level in the design phases, which allows simulation in

which individual responsible positions make decisions and handle exceptions to reduce the decision waiting time (Table 2).

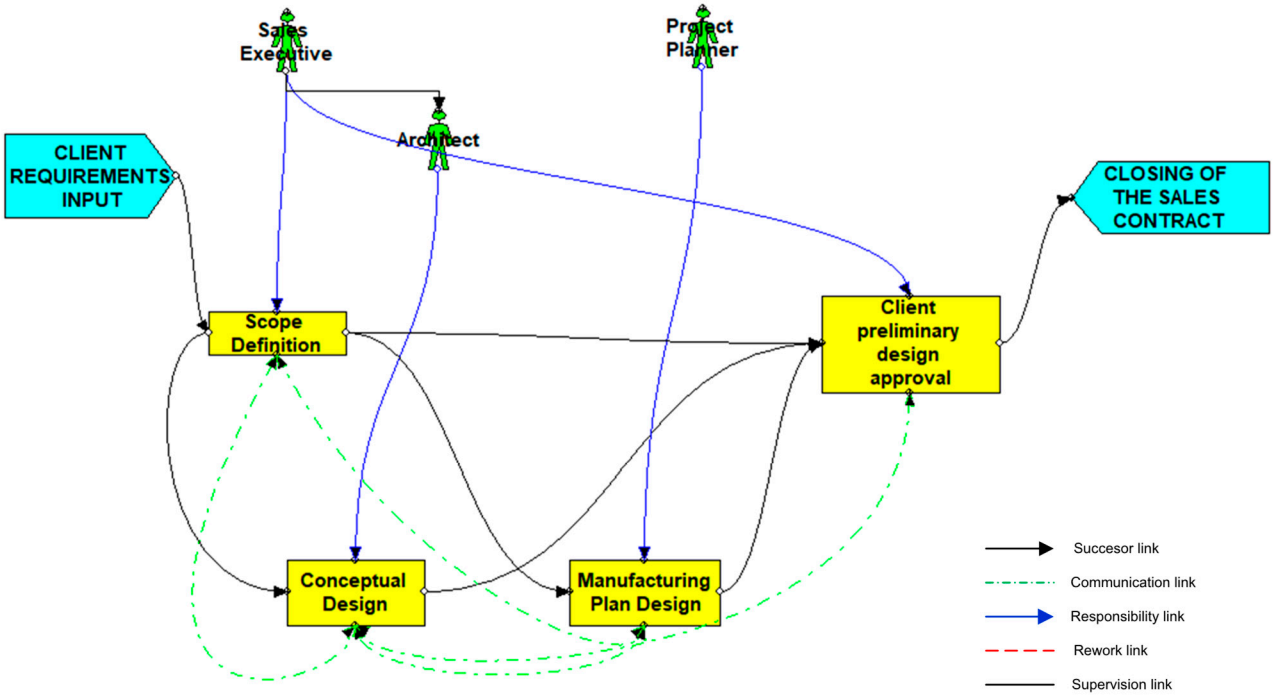


Figure 11. Modified organization of the sales takeoff phase.

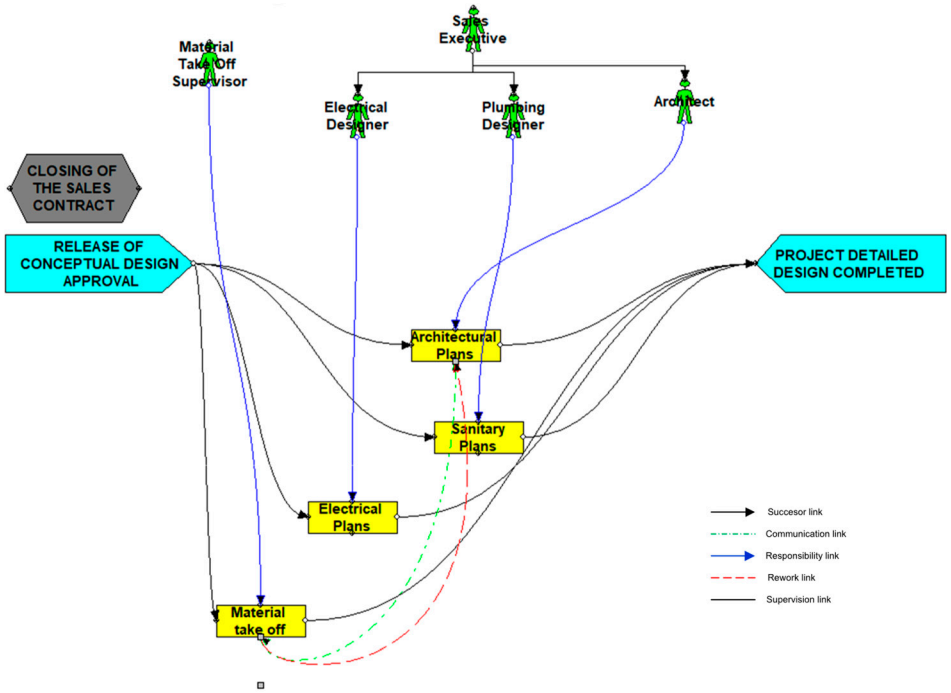


Figure 12. Modified organization of the project's detailed design phase.

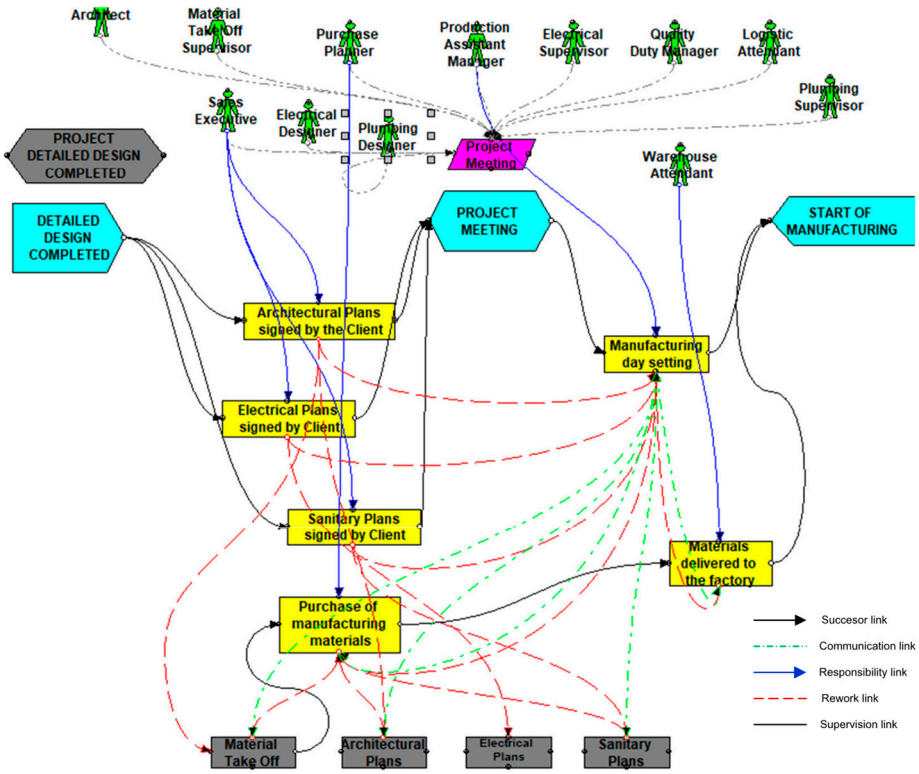


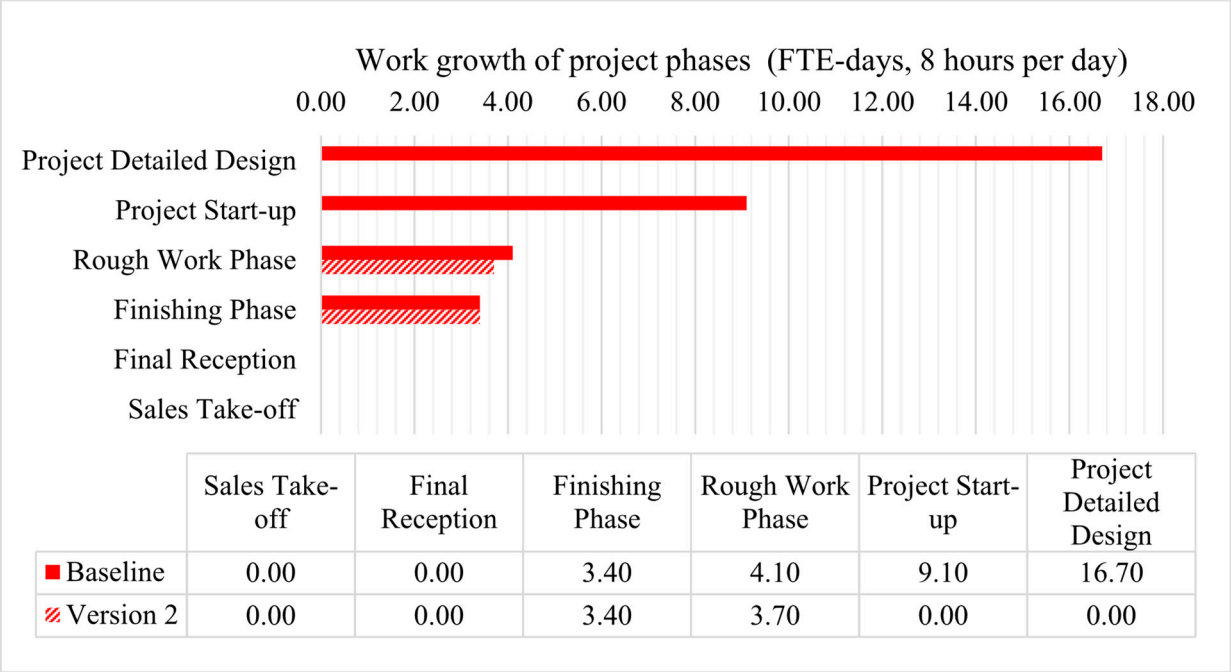
Figure 13. Modified organization of the startup phase.

Table 2. Properties of the VDT model to simulate the modified organization and process characteristics.

Property	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6
Priority	Medium	Medium	High	High	High	Medium
Team continuity	High	High	High	High	High	High
Decision level	Low	Low	Low	Medium	Medium	Medium
Meeting preferences	Medium	Medium	Medium	Medium	Medium	Medium
Cross function team	Medium	Medium	Medium	Medium	Medium	Medium
Task communication	0.2	0.4	0.4	0.6	0.6	0.5
Distraction level	0.25	0.25	0.25	0.25	0.25	0.25
Work complexity	0.1	0.1	0.1	0.1	0.1	0.05
Project uniqueness	0.1	0.1	0.1	0.1	0.1	0.5

The sensitivity analysis results show that the simulated duration is 56.7 days compared to the CPM duration of 69.4 days. This represents a reduction in the project duration by 13 days. Under this scenario of integration in the early phases of the design project, the specialties reduced rework in the project's detailed design and project startup phases.

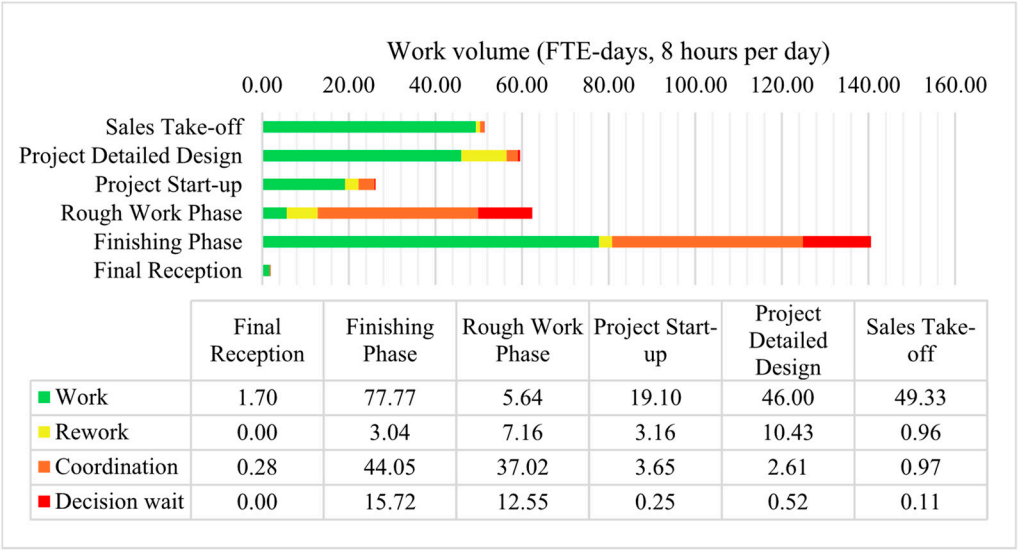
The analysis of phases with significant schedule growth risk reveals that project detailed design and project startup do not impact the duration. The rough work and finishing phases are the only ones with schedule growth risk. However, it is insignificant (lower than 4) (Figure 14).



	Sales Take-off	Final Reception	Finishing Phase	Rough Work Phase	Project Start-up	Project Detailed Design
Baseline	0.00	0.00	3.40	4.10	9.10	16.70
Version 2	0.00	0.00	3.40	3.70	0.00	0.00

Figure 14. Schedule growth risk—VDT's model Version 2.

According to the SimVision results of the modified VDT model, the analysis of the work volume shows that the sales takeoff and finishing phases continue with the longer direct work volume. On the other hand, rough work, project startup, project detailed design, and finishing phases also continue with the highest percentage of indirect work (rework, coordination, and wait volume). However, the rework volume was reduced significantly in the indirect work of project startup and project detailed design (10.43 and 3.16, respectively). Meanwhile, the rough work and finishing phases have a reduction in the coordination (37.02 and 44.05, respectively) and wait volume (12.55 and 15.72, respectively) (Figure 15).



	Final Reception	Finishing Phase	Rough Work Phase	Project Start-up	Project Detailed Design	Sales Take-off
Work	1.70	77.77	5.64	19.10	46.00	49.33
Rework	0.00	3.04	7.16	3.16	10.43	0.96
Coordination	0.28	44.05	37.02	3.65	2.61	0.97
Decision wait	0.00	15.72	12.55	0.25	0.52	0.11

Figure 15. Work volume of the VDT's model version 2.

The reduction in the rework volume reflects the horizontal and vertical integration in the company's organization and process. In this scenario, specialists operate without boundaries among the various organization members, are co-located with other skill

specialists, and work together in the same office to maximize collaboration in the early phases of the design project. Characteristics and practices that describe a fully integrated team [15].

The horizontal and vertical integration among specialties within the design phases (sales takeoff and project detailed design) encourages efficient communication and facilitates collaborative design that helps to detect design errors or changes during the design phases. Therefore, in the manufacturing phases, there is less probability that corrective iterations occur due to exceptions that require work already completed to be redone in the definition and design phases. Hence, this explains the reduction in the rework volume in the project's detailed design and the project's startup phases.

Therefore, the VDT simulation results support the position that integration is desirable in improving project performance and is aligned with previous seminal results [16,17,23,64]. These results show an opportunity for the industrialized company to implement strategies encouraging the integration of its stakeholders and processes. These integration strategies will allow the company to reduce the rework that exists in the project organization and process, resulting in an improvement in the project's performance.

6. Conclusions

This study uses a combination of empirical case study and theoretical simulation to examine the impact of intra-organization fragmentation and stakeholder integration on project performance in an industrialized timber building company. The VDT model captures the reality of the company's organization and process to build a fictional modular office project, considering the same standard components and processes the company uses. This research applied a combination of empirical data and simulation modeling to evaluate the company's organization and process dynamics of fragmentation and integration and to measure the project performance in terms of four types of work: direct, coordination, rework, and waiting.

The analysis of the VDT conceptual model showed vertical and horizontal fragmentation across the design and manufacturing phases. The VDT simulation results revealed that the isolated work, poor communication and coordination, and the fragmentation of expertise and knowledge between the design and manufacturing phases led to significant rework and waiting volume, generating a project duration 34 days behind schedule.

The second version of the VDT model showed that introducing organizational strategies: (1) co-location of multidisciplinary teams during the early design phase, (2) inclusion of manufacturing specialties in the project startup phase, and (3) reduction in the decision level in the design phase to make decision and handle exceptions, produced improvements in project performance.

The research results emphasize the relevance of generating vertical and horizontal integration at an intra-organizational level. The critical role of early collaborative involvement of all disciplines emphasizes that integrated organizational structures and processes are essential for ensuring reliable project outcomes in industrialized timber building companies. The research offers empirically grounded insights that underscore the value of integration strategies in industrialized construction and serves as a foundation for future studies aiming to formulate structured frameworks for integration-driven improvements.

Although the empirical data collection and the development of the VDT model were achieved successfully, the current research still has some limitations. The VDT model was created based on the experience of one industrialized timber building company, which allowed the authors to make an analysis combining an empirical case study and theoretical simulation analysis. In future research, it would be advisable to include more

similar companies to make a comparison analysis about intra-organization integration and fragmentation.

Another limitation is that the analysis of the organizational changes in the second version of the VDT model measured project performance using duration and direct, coordination, rework, and waiting work. Other factors, such as quality and risk, should be considered in the analysis. Future research should study how these factors are affected by the organizational and process properties of the VDT model.

Even though the authors used a systematic method to capture the company's organization and process, the SimVision software has some limitations regarding capturing dynamic team interactions and informal communications. Hence, it would be advisable for future research to study how informal communications and dynamic team interactions throughout the life cycle impact the project performance.

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Abbreviations

The following abbreviations are used in this manuscript:

VDT	Virtual Design Team
AEC	Architectural, Engineering, and Construction

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