Assessing the Financial Dynamics of Modular Offsite Building Projects

Hisham Said[1], Tarek Salama[2], and Anthony Gude[3]

[1] School of Engineering, Santa Clara University, Santa Clara, California, USA
[2] Department of Construction Management, California State University Sacramento, Sacramento, California, USA
[3] Gude Capital management
hsaid@scu.edu, salama@csus.edu, agude@gudecapital.com

Abstract –

Current project development financial modeling approaches have been utilized for traditional stick-built construction. This paper presents a novel system dynamics simulation model to analyze the financial dynamics of modular offsite building projects. The model captures the complex interactions between construction activities and cash flows, allowing for the evaluation of various financial parameters of developers. The developed model was applied to a real-world case study, demonstrating alignment with traditional financial models. Sensitivity analysis revealed the significance of specific parameters in influencing project profitability, such as factory deposit ratio, equity capital ratio, and interest rates. These findings provide valuable insights and strategies to enhance the financial attractiveness of modular construction projects. The paper contributes to the body of knowledge by offering a comprehensive tool for studying the financial implications of modular construction projects. This tool can assist stakeholders in making informed decisions and optimizing project outcomes, thus promoting the growth and adoption of modular construction as a sustainable and efficient building approach.

Keywords – Modular Construction; Offsite; System Dynamics; Simulation; Financial; Modeling.

1 Introduction

Smart manufacturing, automation, and industrial production (prefabrication, and offsite manufacturing) are main technologies involved in the Industry 4.0 (I4.0) revolution [1]. I4.0 is defined as an 'integration of technologies that reshapes the way things are made' [1]. Construction 4.0 represents the Industry 4.0 version for the construction industry by digitization using the following three transformational trends: 1) Industrial production and construction (offsite manufacturing, 3D printing, and automation); 2) Cyber-physical systems (Internet of things (IoT) and sensors); 3) Digital technologies (Building information modeling (BIM), artificial intelligence (AI), big data, Blockchain, augmented reality, cloud computing, and laser scanning, etc. [1]. Modular and offsite construction (MOC) systems are classified based on size of prefabricated components into prefabricated and processed materials, panelized (2D modules), modular (3D modules), and hybrid construction (combination of 2D and 3D modules) [2,3]. Modular and offsite construction (MOC) provides many advantages due to its competency in delivering better quality, lower cost, shorter schedules, and higher safety [4,5]. However, modular and offsite construction is known by its unique risks and uncertainties, which can be different from those of traditional construction [6]. Hence, the modular and offsite construction industry is facing many obstacles and barriers and not all modular construction projects were delivered successfully [7]. However, according to the modular building institute (MBI), the market share for permanent modular construction as a percentage of the total construction industry increased from 2.14% in 2015 to 6.03% in 2022 [8]. Many studies investigated the barriers to increase the market share for modular and offsite construction [3,6,9,10]. Salama et al. [3] investigated five main barriers determined by industry professionals using a questionnaire to collect data for: 1) the negative stigma for modular and offsite construction; 2) the lack of examples of past success in this industry; 3) the lack of standards and regulations. 4) the unclear procurement strategies utilized in this industry; and 5) project financing obstacles. While other studies assessed the risks associated with this industry [11,12]. Li et al. [11] identified modular risks such as engineering, occupational and cultural, socio-economic, and financial risks and a fuzzy analytic hierarchy process (AHP) was utilized to rank these risks; then simulation techniques were used to assess risks of modular projects. Abdul Nabi and El-adaway [12] developed a new approach to forecast the cost performance of modular construction projects after identifying 50 modular risks that include risks for material supply, transportation, manufacturing installation, contracts and disputes. This study also included financial risks such as the high initial (capital) costs and the inconsistent cash flow. Moreover, many offsite construction companies are providing good examples of success [8], however, in certain markets, this industry is still immature and encounters financial obstacles that might lead to disputes in modular construction projects [13,14]. Hence, this research is investigating the effect of different financial parameters that can be changing based on the current economic challenges existing in the market using a newly developed system dynamics model to simulate different scenarios for these financial parameters.

2 Literature review

Cameron and Carlo [15] used spreadsheets to perform an assessment for the impact of using modular construction on the equity internal rate of return (IRR), which is the annual rate of return for investment in a specific period of time. This study compared modular and traditional construction by having two scenarios for six buildings. The first scenario assumes these buildings are constructed for rent, while the second is assuming it is constructed for sale. It was concluded that the equity IRR increased from 35.1% to 47.5% for the first scenario when utilizing modular construction compared to traditional construction, while the increase for the second scenario was from 25.75 % to 27.60 %. However, this study did not investigate the effect of changing financial parameters such as the lending interest rate, debt to equity ratio, or the time period of the cash flow. Velamati [16] compared between modular and traditional construction for a case study of a 20-story high rise building in a major east coast project, and it was concluded that the annual IRR for modular construction is 22 % which is higher than the IRR for traditional construction which was 20.44%.

Cazemier [17] performed a comparative financial analysis between a cross laminated timber (CLT) building offsite construction, and traditional steel and concrete building in Australia. This study used the EstateMaster software to input financial parameters such as construction cost, interest expenses, land purchase price, construction contingency, land purchase price, sales revenue, and professional fees to investigate its effects on profit indicators such as IRR, return on equity (ROE) – the total amount of return received for original investment –, development margin, and development profit. It was concluded that CLT developments may result in lower development margin, development profit, and ROE, but it increases equity IRR due to the shorter timeline schedules for offsite construction.

Salama et al. [4] presented a comprehensive literature review for the challenges that any modular developer may encounter to finance MOC projects. These challenges include: 1) the large upfront capital requirements which make manufacturers ask for upfront payment of around 50 percent in advance to purchase materials and if the developer is acquiring this funding from banks, then the current high interest rates would reduce the IRR; 2) perception of ownership: since banks don't issue funding installments until the onsite installation of modules which increase the financial burden for any modular builder; 3) the immature market for MOC since many developers are lacking the experience in this industry while facing uncertainties in scheduling and pricing due to the current supply chain issues and fluctuation in material prices; 4) progress monitoring for manufacturing is considered an increased risk for financing MOC by banks compared to than traditional construction projects; 5) lack of support from authorities and financial sector for MOC industry which makes modular manufacturers pay for materials and then for manufacturing while construction financing is released after modules are delivered to construction site; 6) lending interest rates for MOC are higher than traditional construction since several banks lack the full understanding for it, hence this fact is affecting the IRR for any modular developer; 7) financial impact for using MOC can be different from country to another due to many factors such as the differences in labor costs and the different economical situations between countries; 8) transportation and storage costs might not be considered by lending banks while securing construction financing; 9) Some projects which are publicly funded might not allow some payments certifications in a timely manner for MOC. However, Salama et al. [4] did not conduct a quantitative analysis for assessment of utilizing modular construction on the internal rate of return (IRR) for modular developers.

Assaf et al. [18,19] developed an automated cash flow system that mitigates a number of MOC financial barriers using advanced technologies, such as building information modeling (BIM), blockchain, and smart contracts. However, this study focused on developing an automated payment system MOC projects that consider different procurement approaches more than focusing on financial modeling for MOC to investigate the effect of financial parameters on enhancing the profitability of MOC projects.

3 Research Goal and Methodology

The goal of this study is to develop a novel simulation model to assess the financial dynamics and outcomes of modular offsite building projects. The proposed model would fill the existing research gaps due to the lack of theoretical understanding and the modeling approaches to comprehend the unique financial implications and requirements of offsite construction projects. System dynamics (SD) modeling [20] was utilized to develop the proposed financial model to account for the time-delayed complex causal loops between the construction work (both offsite and onsite) and the resulting cash flow [21, 22]. System dynamics is a mathematical modeling technique that uses stocks, flows, internal feedback loops, and time delays to understand the nonlinear behavior of complex systems over time. It's a computer-based approach for strategy development and better decision making in complex systems.

To achieve this goal, the study methodology involved three steps. The first step is to develop the prefabrication-construction dynamics (PCD) module that captures the progress of the offsite and onsite work scopes and their resulting expenses. The second step is the development of the cashflow dynamics (CFD) module that accounts for the project financing and revenue cash flows in addition to the construction expenses from the first module. The third step of this study is the validation of the SD model using a real modular project. It should be noted that the two SD modules are interconnected, as explained later. The two modules were implemented in the same SD model using AnyLogic 6.9.0 simulation software.

4 Prefabrication-Construction Dynamics Module

The PCD module was developed around the progress in three main work packages: modular units, site work, and building finishes. The first work package includes the fabrication and installation of the prefabricated modular units. The second package covers the site work, which mainly includes the earthwork, foundation, utilities, pavement, and landscape. The third work scope includes any building finishes that were not done in the prefabricated modules, such as building systems, painting, flooring, facade, windows, doors, etc. As shown in Figure 1, each of these scopes is modeled using stocks (rectangles), flows (arrows with valves), input parameters (small circles with black triangle), and auxiliary variables (circles). All three work scopes start with a work-in-progress (WIP) stock element (*Factory_WIP*, *Site_WIP*, *Finish_WIP*), which holds 100% value of progress at the beginning of the simulation run. Afterwards, the progress in each work scope is modeled using flow elements that transfer the scope from WIP stocks to completed work stocks. The site work scope progress is simulated using the *SiteRate* flow from *Site_WIP* to *FinishedSiteWork* stocks, and its units are % of work completed per time unit (month). The finishes work scope progress is similarly simulated using the *InteriorRate* flow and the *completedFinishes* stock. However, the work scope of the prefab modules is simulated using more flows (i.e. *ProdRate* and *InstallRate*) and stocks (i.e. *FinishedModules* and *InstalledModules*) to model the fabrication and installation steps. Each work flow is calculated using background functions that consider the following input data: 1) a work rate curve that defines the expected progress rate at a given work completion level; and 2) a table of productivity coefficients for each month to account for holidays and weather impacts. In addition, the value of each flow is controlled by either time or precedence conditions. The *SiteRate* flow will be forced to be null until the simulation time reaches construction planned start time (i.e. *siteStartTime*) to mark the time of the contractor's access to the site and ability to perform the site work. The *ProdRate* flow will be null until a specific amount of site work progress is achieved (i.e. *FinishedSiteWork >= SiteWorkToProd*) to allow for enough buffer between site and offsite operations. The *InteriorRate* flow will be activated after a specific amount of prefab unit installation is achieved (i.e. *InstalledModules >= InteriorAfterModules*).

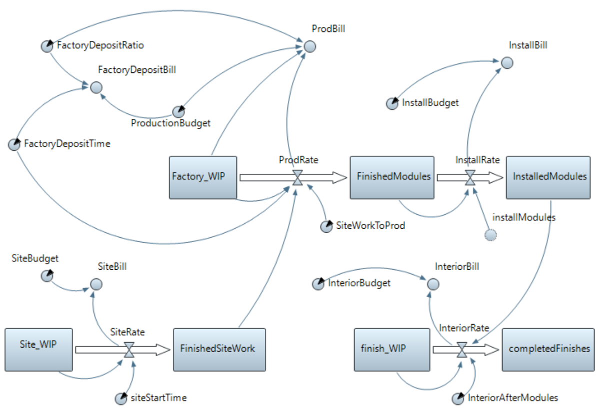

Figure 1. The system dynamics module of the offsite and onsite construction scopes

The model also calculates the construction expenses based on the progress achieved in each work scope. For example, the auxiliary variable *SiteBill* calculates the expenses from the performed work by multiplying the current *SiteRate* value and the inputted *SiteBudget*. A similar logic is used for *InteriorBill*, which is the multiplication of *InteriorRate* and *InteriorBudget*. However, the value and timing of the module production expense billing depends on the deposit payment to the manufacturer to purchase the necessary material (*FactoryDepositBill*). This means that no production billing can be made until achieving a progress that is equivalent to the received down payment. The deposit payment value accounts for the ratio of this deposit (*FactoryDepositRatio*) to the total module production budget (*ProductionBudget*) and the time of making this deposit payment (*FactoryDepositTime*). These construction expense auxiliary variables will be used in the project cash flow dynamics module, as explained in the next section.

5 Cashflow Dynamics Module

The CFD Module simulates the flow and accumulation of equity, debt, expenses and revenue of the development of the modular building project. As shown in Figure 2, the module utilizes three main stock elements: *Equity*, *Debt*, and *NetCashFlow*.

The *Equity* stock accumulates the *Investment* flow, which can be done in a single installment or multiple installments. The *Equity* invested in the project equals the multiplication of *EquityCapitalRatio* (usually 30 - 70%) and the total capital required for the project *projCapital* (which is the summation of all construction-related budgets).

On the other hand, the *Debt* stock element accumulates two flows (*DebtDraws* and *Interest*) and is reduced by a third flow (*LoanPayoff*). The debt draws *DebtDraws* from the project creditor are calculated as a function of the debt-share of the capital (using *EquityCapitalRatio* and *projCapital*) and the schedule setup of these draws (using *firstDebtDrawTime*, *freqDebtDraw*, and *nDebtDraws*). The Interest flow element calculates the amount of interest in each month based on the current *Debt* level and the *interestRate* value. This project interest rate is usually reduced through refinancing from a higher rate *constrInterestRate* during construction to a lower rate *permInterestRate* once the building is operational. Finally, the *Debt* is serviced using the *LoanPayoff* flow element, which pays off only the due interest on any non-negative values of the *Debt* until the sale time of the constructed property (*saleTime*).

The *NetCashFlow* stock simulates the net accumulation of two positive flows (inflows) and three negative flows (outflows). NetCashFlow increases by accumulating: 1) the capital deposits (*CapitalReceipts*) during the construction time; and 2) the generated *NetIncome* from operating the building (when the level of the *CompleteFinishes* reached the targeted *SubstainCompletion*) and selling it at an expected sale time. The value of the *CapitalReceipts* equals the summation of all equity and debit installments made to finance the project, i.e. the values of *Investment* and *DebtDraws* flows. NetCashFlow decreases by deducting: 1) the construction expenses (*ConstructionBills*) are calculated monthly from the PCD module; 2) the expenses related to the land purchase and soft-cost pre-construction items (design, permitting, marketing); 3) the debt repayment (*DebtPayments*).

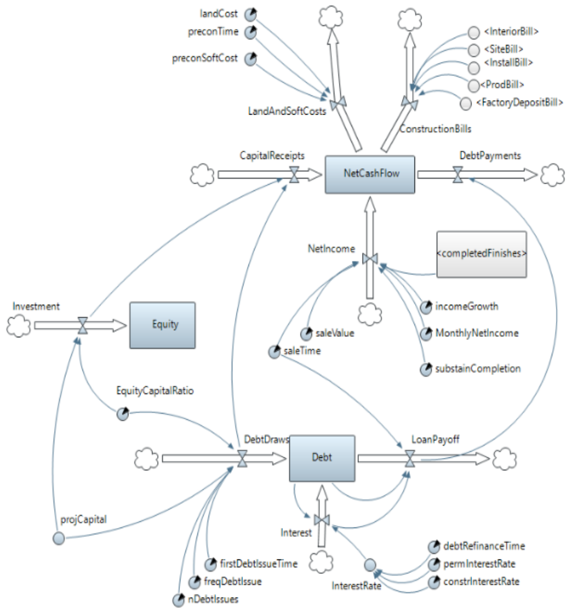

Figure 2. The system dynamics module of the project cashflows

6 Case Study Analysis

The developed SD simulation model is applied to a real case study of a modular residential building project to verify its correctness and validate its relevance. The project is located in California, USA, which entails constructing a 0.4-acre lot into a 74-unit apartment building. Table 1 lists the main time and cost input data of the case study. The debt is structured as follows: a) the first debt draw will happen in the 3rd month, followed by 20 monthly draws; b) the construction debt and permanent debt monthly interest rates are 0.46% and 0.375%, respectively; c) the construction debt will be refinanced in the 30th month using the permanent debt; d) only the monthly interest (both construction and permanent) will be paid without paying for the loan principal amount; and e) the permanent debt will be paid fully when the property is sold (after 84 months).

Table 1. Case study main input data

Input data	Value
Module production budget	\$5,264,570
Module installation budget	\$532,890
Site work budget	\$2,304,954
Finishes budget	\$1,084,940
Land cost	\$6,352,900
Soft (preconstruction) cost	\$537,000
Factory deposit time	0
Factory deposit ratio	0.50
Site work progress rate	8% /month
Module fabrication progress rate	7.5% /month
Module installation progress rate	20% /month
Finishes progress rate	10% /month
Substantial completion	100%
Equity/Capital Ratio	0.45
Preconstruction time	10 months
Time to start site work	5th month
Property net income	\$94,213/month
Property income growth	0.2% /month
Time to sell the property	84 months
Property sale value	\$23,553,055

The SD simulation output closely matched the spreadsheet-based financial model of the project and provided additional insights and visualization of the construction progress and financial feasibility. Figure 3 depicts the recorded levels of four intermediate and final stock elements in the PCD module: *FinishedSiteWork*, *FinishedModules*, *InstalledModules*, and *CompletedFinishes*. All construction scopes were concluded in the 33rd month. The level of the *FinishedModules* stock stopped its accumulation at the 20th month as it hit a 60% progress milestone, which marked the start of the module installation work. On the financial side, the SD model was run for two cases: the base case as described before, and the base case with no factory deposit. This is due to the fact that the authors had access to the spreadsheet-based financial model that did not account for a factory deposit. The SD model matched the spreadsheet model in the calculated value of the annual internal rate of return (IRR), which was found to be 14.7%. However, a lower IRR value of 13.4% was calculated when accounting for a 50% factory deposit payment (i.e. half of the fabrication budget is paid at time 0). Furthermore, the net cash level from the SD model (i.e. the level of the *NetCashFlow* stock) was visualized as shown in Figure 4 to highlight the timely implications of waiving or requiring factory deposits. Without the factory deposit, the developer will experience cash shortage between the 30th and 40th months, which need to be covered by additional equity investment or loans. On the other hand, a 50% factory deposit will result in an additional period of negative cash levels with much larger need for capital in the first 10 months.

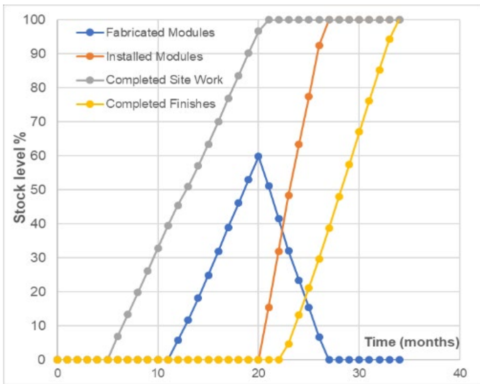

Figure 3. The levels of the major construction work stocks of the analyzed case study

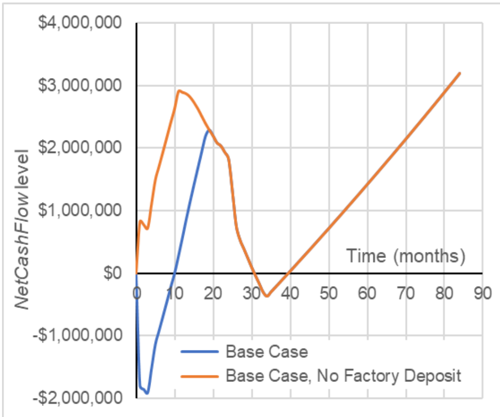

Figure 4. The level of the *NetCashFlow* stock of the analyzed case study under the base case with factory deposit and the same case without the deposit

A sensitivity analysis was performed to further validate the developed SD model and obtain in-depth insights on the influence of different input parameters on the financial outcomes of modular building projects. The previous base case was compared to the +50% and -50% changes in four major financial parameters: factory deposit ratio (*FactoryDepositRatio*), equity/capital ratio (*EquityCapitalRatio*), construction loan interest rate (*constrInterestRate*), and permanent loan interest rate (*permInterestRate*). The other model parameters were not considered in the sensitivity analysis as they are either influenced by the construction plan (fabrication, preconstruction, construction) or the property real estate attributes (property income and sale). Figure 5 shows the sensitivity chart of the IRR value with respect to the change in these four parameters. None of the considered changes resulted in a negative IRR, but it was found that the profitability of the project is the most sensitive to the change in the equity/capital ratio. Positive and negative 50% changes in the equity/capital ratio value resulted in the IRR value to change to 11.4% and 16.8%, respectively (compared to 13.4% for the base case). It should be noted that low IRR values indicate a profitable project, but the project may not be profitable enough for the developer if IRR is less than their minimal attractive rate of return (MARR). Also, Figure 6 shows the net cash level charts of the sensitivity analysis cases. The equity/capital ratio value had also the biggest impact on the net cash levels of the project. For example, a -50% change of the equity/capital ratio (i.e. 0.225) resulted in a significant negative cash period at the beginning of the project. This negative cash period has to be covered by the developer's own equity, which resulted in the drop in the IRR value to 11.4%.

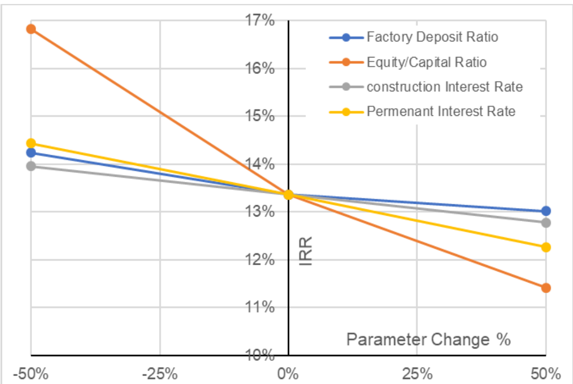

Figure 5. The sensitivity of the internal rate of return (IRR) for the change in four financial parameters

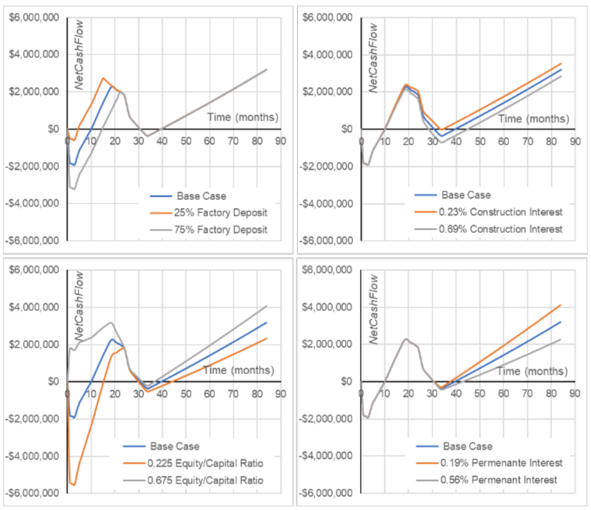

Figure 6. The sensitivity of the *NetCashFlow* level to the changes in the analyzed financial parameters

7 Discussion

The successful application of the SD simulation model to the modular residential building project is evidenced by its close alignment with the spreadsheet-based financial model. The model not only validated the correctness of the financial projections but also offered valuable insights and visualization tools to enhance the understanding of construction progress and financial dynamics. The recorded levels of intermediate and final stock elements provided a visual representation of the project's progression. Notably, the SD model accurately captured the milestones, such as the cessation of *FinishedModules* accumulation at the 20th month, marking the commencement of module installation work. The model's alignment with the spreadsheet model in calculating the annual internal rate of return (IRR) at 14.7% instills confidence in the reliability of the simulation. Introducing a 50% factory deposit payment revealed a nuanced financial landscape. The lower IRR of 13.4% suggests the importance of considering financial strategies related to factory deposits. This observation is further supported by the sensitivity analysis, which also revealed a higher sensitivity to the equity/capital ratio. Increasing the dependency on equity degrades the project's returns, but it is also necessary to cover the negative cash periods of the project due to the hefty deposit required in most modular projects. The combined impact of increasing the factory deposits and the accompanying increase of equity investments results in the deterioration of the financial appeal of modular building projects.

The large upfront capital requirements from manufacturers of modular offsite building projects is one of the main hurdles faced by this industry [4]. Manufacturers ask for an upfront factory deposits of around 50 percent to procure materials in a short period of time for enhancing efficiency of manufacturing [23]. This required large factory deposits from manufacturers may have an effect on bank reserves, hence institutional lenders and banks may require any collateral to reserve some funding on their equity for avoiding regulators' scrutiny [24]. However, Cameron and Carlo [15] conducted an analysis to investigate the impact of utilizing modular construction on the IRR compared to using traditional construction while studying two different scenarios. The first scenario was for a project that includes six buildings which is utilized as rent development, while the second is for the same project but it would be constructed for sale. For first scenario, The IRR was found to increase for the case of using modular construction compared to traditional construction from about 35.1% to 47.5%, and from 25.75 % to 27.60 % for the second scenario. The reason behind the difference between IRR in both scenarios is due to the rental income for part of the development. Cazemier [17] conducted another financial analysis by comparing a cross laminated timber (CLT) project that was using offsite construction technologies, and traditional steel and concrete building. The CLT project resulted in less development profit, and return on equity (ROE), however the IRR increased due to the reduced investment timeline schedule for offsite building projects compared to traditional construction.

This study contributes to the current body of knowledge by developing a simulation-based model for analyzing the financial performance of modular building considering the complex dynamics and dependencies between the construction and cash flows. The model quantifies the impact of some project financial parameters that have been hypothesized to hinder the growth of the modular building industry due to its disadvantaged setup of higher capital needs early in the project development periods. The model can benefit the current construction practice at different levels, where modular building developers can utilize it to produce more holistic financial projection of their projects and the industry advocating organization can better communicate the need for public policies and incentives to support the rapid delivery of housing through modular building approaches.

8 Conclusion

This study's goal was to develop a simulation-based model for evaluating the financial aspects of modular construction by considering the intricate interactions and dependencies between construction and cash flows. The proposed model quantifies the effect of financial parameters that have been theorized to impede the development of the modular construction sector due to its unfavorable structure of significant early capital requirements. By utilizing a system dynamics (SD) modeling approach, the study examined the impact of variables including factory deposit ratio, equity/capital ratio, and interest rates on the internal rate of return (IRR) for developers in this industry. The model's application to a real-world modular residential building project illustrated its accuracy in aligning with traditional financial models and provided insights into construction progress and cash flow dynamics. Sensitivity analysis further highlighted the significance of specific financial parameters in influencing project profitability. The findings suggest the need for strategies to optimize the equity/capital ratio and mitigate the impact of upfront factory deposits to enhance the financial attractiveness of modular construction projects. Overall, the SD model provides a valuable advanced tool for developers to study different financial scenarios for modular projects and visualize cash flow. Recommendations were drawn for enhancing developer profit represented in an optimized IRR. It is noteworthy that the broad application of the proposed tool may be limited due to the fact that the construction and real estate industries are not accustomed to using simulation modeling in their practice. As such, the tool is used to generalize observations on the financial modeling of modular building development projects, which can be considered in the industry practice and their existing computer tools. Despite the insights from the sensitivity analysis, advanced stochastic analysis is needed to examine the concurrent interdependent changes in the model parameters. Finally, the study could benefit from considering additional factors such as government incentives, the impact of economies of scale, and the effect of different procurement strategies on financial outcomes.

Acknowledgment

The authors of this paper acknowledge the Research and Creative Activity award (RCA Faculty Awards Program) awarded by Faculty Senate's Research and Creative Activity Subcommittee in California State University, Sacramento for their support to this research.

References

[1] Sawhney, A., Riley, M., Irizarry, J., & Riley, M. Construction 4.0: An Innovation Platform for the Built Environment. Routledge publishing, Taylor & Francis Group, 526 pages, ISBN-13 : 978-0367027308, 2020.

[2] Salama, T., Salah, A., Moselhi, O. and Al-Hussein, M. (2017), “Near optimum selection of module configuration for efficient modular construction.”, Automation in Construction, Vol. 83, pp. 316-329.

[3] Salama, T., Moselhi, O. and Al-Hussein, M. Overview of the characteristics of the modular industry and barriers to its increased market share. International Journal of Industrialized Construction, Vol. 2 No. 1, pp. 30-53, 2021.

[4] Salama, T., Figgess, G., Elsharawy, M. and El-Sokkary, H. Financial modeling for modular and offsite construction. Proceedings of the International Symposium on Automation and Robotics in Construction, Vol. 37, pp. 1082-1089, Kitakyushu, Japan, 2020.

[5] Salama, T., and Said, H. Agility assessment framework for modular and offsite construction.”, Construction Innovation, https://doi.org/10.1108/CI-09-2022-0238, 2023.

[6] Wuni, I.Y. and Shen, G.Q. Barriers to the adoption of modular integrated construction: Systematic review and meta-analysis, integrated conceptual framework, and strategies. Journal of Cleaner Production, 249, p.119347, 2020.

[7] Choi, J. O., J. T. O'Connor, and T. W. Kim. Recipes for cost and schedule successes in industrial modular projects: Qualitative comparative analysis. Journal of Construction Engineering and Management, 142 (10): 04016055.2016. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001171.

[8] The Modular Building Institute (MBI). Permanent Modular Construction Report, 39 pages, 2023. https://www.modular.org/industry-analysis/

[9] Gusmao Brissi, S., Debs, L. and Elwakil, E. A review on the factors affecting the use of offsite construction in multifamily housing in the United States. *Buildings*, *11*(1), p.5, 2020.

[10] Navaratnam, S., Satheeskumar, A., Zhang, G., Nguyen, K., Venkatesan, S. and Poologanathan, K. The challenges confronting the growth of sustainable prefabricated building construction in Australia: Construction industry views. Journal of Building Engineering, 48, p.103935, 2022.

[11] Li, H.X., Al-Hussein, M., Lei, Z. and Ajweh, Z. Risk identification and assessment of modular construction utilizing fuzzy analytic hierarchy process (AHP) and simulation. Canadian Journal of Civil Engineering, 40(12), pp.1184-1195, 2013.

[12] Abdul Nabi, M. and El-adaway, I.H. Risk-based approach to predict the cost performance of modularization in construction projects. Journal of Construction Engineering and Management, 147(10), p.04021133,2021. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002159

[13] Salama, T. and Said, H. Agility assessment framework for modular and offsite construction. Construction Innovation Journal , 2023. *https://doi.org/10.1108/CI-09-2022-0238*.

[14] Abdul Nabi, M. and El-adaway, I.H. Understanding disputes in modular construction projects: Key common causes and their associations. Journal of Construction Engineering and Management, 148(1), p.04021184, 2022. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002208

[15] Cameron, P.J. and Di Carlo, N.G., Piecing together modular: understanding the benefits and limitations of modular construction methods for multifamily development (Doctoral dissertation, Massachusetts Institute of Technology), 2007.

[16] Velamati, S. Feasibility, benefits and challenges of modular construction in high rise development in the United States: a developer's perspective, Master of Science, Dept. of Architecture, Massachusetts Institute of Technology, On-line: http://hdl.handle.net/1721.1/77129, 2012.

[17] Cazemier D. Comparing cross laminated timber with concrete and steel: a financial analysis of two buildings in Australia. Modular and Offsite Construction (MOC) Summit Proceedings, 2017.

[18] Assaf, M.K.A., Financial management and procurement approaches of modular construction projects: a blockchain-based bim framework. Master of Science thesis, the Hong Kong polytechnic university, 2022.

[19] Assaf, M., Hussein, M., Alsulami, B.T. and Zayed, T. A Mixed Review of Cash Flow Modeling: Potential of Blockchain for Modular Construction. Buildings, *12*(12), p.2054, 2022.

[20] Sterman J. D. (2000). Business Dynamics: Systems Thinking and Modeling for a Complex World. Irwin/McGraw-Hill, New York, NY.

[21] Dabirian, S., M. Ahmadi, and S. Abbaspour. 2021. "Analyzing the impact of financial policies on construction projects performance using system dynamics." Engineering, Construction and Architectural Management, 30 (3): 1201–1221. Emerald Publishing Limited. https://doi.org/10.1108/ECAM-05-2021-0431.

[22] Khaledi, H. (2015). "A Generic System Dynamics Model of Firm Internal Processes." Proceedings of the 33rd International Conference of the System Dynamics Society, System Dynamics Society, Cambridge, Massachusetts, USA -- July 19-23, 2015, ISBN: 9781510815056.

[23] Galante C, Draper-Zivetz S, Stein A. Building Affordability by Building Affordably: Exploring the Benefits, Barriers, and Breakthroughs Needed to Scale Off-Site Multifamily Construction. Terner Centre for Housing Innovation, UC Berkeley. Online: http://ternercenter.berkeley.edu/uploads/offsite_construction.pdf, 2017.

[24] Maher A. Breaking with tradition. Special report from AVANA capital. 2018 https://avanacapital.com/wpcontent/uploads/Expert-Speak-Finance-HT_MARCH_ISSUE_-2018.pdf.