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Exploring the Use of 4D BIM and the Last Planner System® with Parametric Design Tools in Lean Construction and Control Learning Settings

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Abstract

Question: How do students perceive a novel, simulation-based approach to teaching the Last Planner System in construction management education?

Purpose: The purpose of this study is to introduce a new pedagogical strategy for teaching the Last Planner System and to assess its impact on students' perceptions of learning and practical applicability.

Research Method: This study employs a role-playing exercise in which students use traditional sticky notes and advanced 4D visualization tools for Look-Ahead Planning (LAP) in a classroom setting. A post-activity survey quantitatively assesses students' perceptions across multiple dimensions, including engagement, usability, motivation, and learning relevance

Findings: By applying advanced visualization tools, this research presents a new method for teaching the Last Planner System. Findings suggest students viewed the approach positively, emphasizing its clarity and practical value.

Limitations: The study had a small sample size and was limited to the classroom setting, which may affect the generalizability of the findings. This initial phase focuses on acceptability of the technology, as study design does not seek to measure learning outcomes directly.

Implications: The findings suggest that integrating advanced visualization tools within construction education can support students' understanding of complex concepts and may improve collaborative planning skills. This approach could be extended to other

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educational contexts and professional training programs.

Value for authors: Integrating visualization tools, such as 4D BIM, with the Last Planner System® offers practical benefits for construction practitioners by enhancing collaboration, decision-making, and workflow visualization, thereby improving overall project outcomes.

Keywords: 4D Visualization, Last Planner System® (LPS®), Construction Workflow Management, Parametric Design Tools, Lean Construction Practices, Look-Ahead planning (LAP), Visual Programming (VP), Construction Education and Training (CEET)

Paper type: full paper

Introduction

While visualization tools have become standard practice in the Architecture, Engineering, and Construction (AEC) industry, their implementation varies significantly in sophistication and effectiveness. Basic methods, such as sticky notes and 2D charts, have traditionally been used for planning and coordination. However, advanced visualization techniques, particularly those that integrate Building Information Modeling (BIM) with 3D and 4D simulation capabilities, provide more powerful tools for understanding and managing construction processes. This evolution from simple visual aids to dynamic simulations represents a shift in how projects are planned, monitored, and executed (Koskela et al. 2023). Simulations serve as a mediating system that helps observers shape what they can see, reason about, and make decisions—e.g., by observing how instances of visual representation (such as the geometries of a 3D model and associated spatial relationships or processes) unfold. Within these evolving technological ecosystems, Lean Construction offers a crucial and complementary management philosophy aimed at maximizing client value and minimizing waste.

Originating from the Toyota Production System (TPS), Lean Construction emphasizes principles such as customer focus, waste elimination, reliable workflows, and continuous improvement through collaboration and feedback (Koskela et al. 2002). The exact definition of Lean Construction varies depending on which principles are prioritized, such as value creation, waste reduction, continuous improvement, collaboration, production management, or adaptation to complexity (Bertelsen 2004, El-Gafy et al. 2008, Mossman 2018). This flexibility fosters diverse perspectives and innovative approaches within the Lean Construction community. In this paper, the authors consider Lean Construction as a specialized application that integrates concurrent product and process design, maintains process control throughout the project's lifecycle, and prioritizes reliable workflow over individual activity optimization.

While Lean Construction provides the philosophical and operational framework for efficiency, BIM serves as a powerful technological enabler of its principles. Although BIM and Lean Construction share the common goal of improving productivity, their development was not conceptualized as an integrated model. Increasingly, however, research highlights the benefits of combining BIM technologies with Lean Construction practices (Sacks et al. 2010, Fosse et al. 2017, Evans and Farrell 2020, Herrera et al. 2021).



When combined with simulation capabilities, BIM's visualization tools, such as 3D and 4D modeling, significantly improve progress monitoring and productivity management across the project lifecycle. Real-time site and as-built modeling enhance decision-making, progress monitoring, and productivity management. By providing accurate and up-to-date visual representations, they enable project stakeholders to communicate more effectively, collaborate efficiently, and make informed decisions. Industry pioneers such as Tocci Building Companies, Skanska, and Turner Construction demonstrated how BIM's 3D/4D modeling supports Lean goals by improving cost estimation, sequencing, and workflow reliability (Khazode et al. 2008).

Nevertheless, despite these advantages, the adoption of advanced visualization and simulation tools has been uneven. Both industry professionals and academics identify deficiencies in simulation training into educational curricula (Leite et al. 2016). Educational institutions have a crucial role in bridging this gap. Spatial visualization and simulation skills are essential for interpreting design concepts, anticipating construction challenges, and communicating effectively. In addition, they are strong predictors of student and professional success (Deno 1995, Miller 1996, Ahmed et al. 2014, Sorby 2015, Williamson and Anderson 2018). Research has shown that integrating advanced visualization tools in the classroom, including BIM-based and Virtual Reality (VR) simulations, significantly enhances these abilities (Perdomo et al. 2005, Glick et al. 2012, Kim and Irizarry 2020, Wang et al. 2022, Abouelkhier et al. 2024).

This study builds on this pedagogical opportunity. It explores how students in a Construction Management program perceive and learn from a novel instructional approach that integrates visual programming and simulation to teach the Last Planner System® (LPS®), a central Lean Construction tool for collaborative planning and control (Rohani et al. 2013). The approach employs Grasshopper, a visual programming tool that operates within Rhinoceros 3D CAD software (Celani and Vaz 2012), to enable students to create 3D objects and time-based (4D) simulations that visualize planning sequences. Unlike traditional text-based coding, visual programming uses graphical elements to represent logic and workflows, aligning closely with Lean's focus on iterative feedback and process visualization. An additional advantage is that visual programming tools, such as Grasshopper, provide an intuitive interface, making easy to use for many users.

The paper presents the results of an evaluation of students' interaction with the technology and the effects of this interaction on learning, providing insights into the potential of advanced visual programming and simulation techniques in construction education. The following section provides an overview of the literature on the incorporation of visualization technology into construction management education. A methodology section follows, outlining the steps and explaining the rationale behind the survey. The next section describes the experiment conducted in the classroom environment and the statistical results. The authors then conclude with a discussion on implications and future research.

Background

In recent years, educators have increasingly turned to advanced digital tools—such as BIM, VR, and simulations—to improve construction management education. These technologies offer new ways to teach complex processes and Lean Construction methods by immersing students in interactive, practice-oriented learning environments. However, applications to the Last Planner System® (LPS®) are limited. This section reviews three related areas of scholarship: (1) technology integration in construction management education, (2) simulation-based teaching of Lean Construction concepts, and (3) BIM-enabled simulations of LPS®.

Technology Integration in Construction Management Education

Traditional teaching methods have been criticized for their lack of engagement practical experience, which limit students' ability to grasp complex details and understand real-world scenarios and challenges in the construction industry (Pedro et al. 2016). To address this, educators are adopting active learning strategies that integrate digital tools, including 4D BIM, Virtual Reality (VR), and simulation-based exercises. 3D BIM is a digital model for visualization that captures the geometric and spatial aspects of a project, 4D BIM extends the model by linking them to time to enable construction sequence and scheduling analysis. VR in construction refers to a computer-based visualization technology that displays a three-dimensional representation of a built environment from a first-person point of view, either on a standard screen (for low levels of immersion) or through head-mounted displays (for high levels of immersion). When used in training and education, it is interactive technology that immerses learners in simulated scenarios where they can practice skills, explore concepts, and receive feedback in real time. In this context, VR is treated as an instructional medium that supports experiential, hands-on learning without exposing learners to the real world. In this setting, users perceive design visualizations at a specific human scale and can navigate in the virtual space as if they were physically present, allowing them to visually explore building elements, spatial relationships, and construction sequences through a walk-through experience.

Although prior studies report benefits for learning and engagement when these tools are used in instruction, their implementation has been uneven, with several barriers slowing the transition from traditional to advanced methods. To facilitate this transition, a comprehensive approach is necessary, encompassing educational initiatives and the gradual integration of new technologies.

Incorporating BIM into construction management education has shown clear benefits, including improved collaborative group work and enhanced learning outcomes (Wang et al. 2022). BIM also facilitates the integration of VR, enabling the creation of immersive virtual environments that give students hands-on experience in simulated construction projects (Sampaio et al. 2010, Ghanem 2022). This immersive approach improves students' understanding of cost, time management, and construction processes (Seyman Guray and Kismet 2022). For instance, these technologies have been used to enhance hazard recognition and safety training (Alizadehsalehi et al. 2019, Zhou et al. 2023). Studies also demonstrate



that students show improved error detection capabilities when using BIM-based VR simulations compared to traditional 2D drawings

When integrated with BIM, Visual Programming (VP) can be an effective approach for supporting construction management tasks, especially in the design and composition of complex systems. This coupling contributes to the gradual integration of learning and engagement technologies in constructivist management education. Visual programming is a method that uses graphical elements, such as icons, diagrams, and flowcharts, to create and manipulate code rather than traditional text-based programming. By automating processes such as geometry generation and positional data handling, this integration streamlines workflows and enhances the efficiency of decision-making (Zhu et al. 2020). Moreover, VP and BIM significantly have the potential to improve tasks such as quantity take-off (QTO), ensuring more accurate material quantification and better project planning (Cepni et al. 2021). By leveraging visual programming tools like Dynamo with BIM platforms such as Autodesk Revit, professionals could dynamically link 3D model geometry with spreadsheet data to perform efficient and precise QTO. While these technologies have enhanced engagement, their potential for supporting Lean-specific pedagogy should continue to be explored.

Simulation for Lean Concepts

Simulation has proven effective for teaching Lean Construction concepts (Bhatnagar et al. 2022; Leicht and Drevland 2024). Simulations can teach general Lean principles as well as specific tools like LPS (Warcup and Reeve 2014), Set-Based Design (Ouma et al. 2024) and Target Value Delivery (Desmarais and Alves 2024). By replicating real-world processes, these exercises help students understand cause-and-effect relationships in production systems, resource allocation, and workflow management. Physical models (e.g., LEGO exercises) and digital simulations have been shown to improve engagement, understanding, and retention (Badurdeen et al. 2009, Kuriger et al. 2009, González et al. 2015, Burch V and Smith 2017).

Virtual simulation environments extend this pedagogical model by immersing students in interactive, real-time decision-making contexts. For instance, the VE-Suite virtual engineering framework allows users to experiment with Lean concepts such as Just-In-Time and Little's Law, promoting problem-solving and motivation among students (Cudney et al. 2011, Cudney et al. 2014). Beyond traditional simulations, recent research highlights how Lean is increasingly combined with digital technologies, IoT, AI, digital twins, and automation, to create intelligent, data-driven planning systems (G. M. et al. 2024, Chukwumuanya et al. 2025).

However, existing simulations face limitations. Physical simulations like Lego exercises, while engaging, often focus narrowly on production line concepts (Badurdeen et al. 2009) and may not fully capture the spatial complexity of actual construction projects. Virtual simulations, while more sophisticated, may require significant implementation of resources and technical training (Chukwumuanya et al. 2025). Furthermore, few simulation approaches specifically address the challenge of helping students visualize the spatial and temporal dimensions of construction planning simultaneously.

To synthesize the literature on technology integration and simulation-based approaches to Lean Construction education, Table 1 summarizes key studies, highlighting their pedagogical focus, benefits, and limitations. The table highlights methods ranging from CAD scripting and BIM integration to virtual reality and simulation-based exercises, detailing each approach alongside its primary benefits and notable limitations. This comparison illustrates both the pedagogical advantages of advanced visualization and simulation techniques (e.g., enhanced engagement, improved spatial understanding, and real-time decision-making) and the practical challenges associated with their implementation, including technical complexity, scalability, and accessibility. While these studies demonstrate the potential of immersive and interactive methods for improving student learning, they also reveal gaps, particularly in tools that simultaneously capture the spatial and temporal dimensions of construction planning. These insights underscore the need for educational innovations that combine visual programming with 4D simulations, motivating the approach proposed in this paper to enhance Last Planner System® (LPS®) instruction.

Table 1: Approaches in Construction Management Education and Their Benefits and Limitations

Approaches	Benefits	Limitations	Authors
CAD scripting & visual programming; BIM-based VR; VR/AR for safety training	Supports computational design, links theory to practice, improves hazard recognition	Steep learning curve for non-programmers; high VR hardware requirements; limited site realism	(Sampaio et al. 2010) (Celani and Vaz 2012) (Alizadehsalehi et al. 2019)(Ghanem 2022) (Zhou et al. 2023)
3D interactive visualization and simulation tools	Enhance learning, engagement, and progress tracking	Requires technical skills; implementation and scalability challenges	(Perdomo et al. 2005) (Raphael 2009) (Rohani et al. 2013)
BIM for clash detection, performance evaluation, various dimensions, LPS tool.	Improved error detection, efficiency, visualization, coordination, collaboration.	Technical focus, slow adoption, industry resistance, and training demands	(Glick et al. 2012) (Wang et al. 2013) (Kamardeen 2014) (Čuš Babič and Rebolj 2016) (Moore and Gheisari 2019) (Wang et al. 2023)
4D BIM and Virtual Reality (VR).	Enhanced spatial skills, understanding of sequencing.	High learning curve; VR equipment dependency	(Abouelkhier et al. 2024)
Workflow mapping using Lucidchart.	Improved planning and coordination	Text-based, lacks dynamic context	(Faulkner and Contributor 2018)

Approaches	Benefits	Limitations	Authors
Simulation-based training; Lean simulation games (e.g., LEBSKO); virtual Lean learning environments.	Improves Lean understanding, engagement, motivation, and problem-solving.	Limited scope beyond production lines; scalability and implementation challenges	(Badurdeen et al. 2009) (Kuriger et al. 2009) (Cudney et al. 2011) (González et al. 2015) (Burch V and Smith 2017)
Integration of CSM, LPS®, and BIM.	Improved collaboration, understanding, decision-making.	Industry adoption challenges.	(Wickramasekara et al. 2020)
BIM-based LPS tools for construction management	Improves planning, productivity, and waste reduction.	Requires addressing technical training.	(Heigermoser et al. 2019)

Simulations using BIM and LPS®

The convergence of BIM simulation capabilities with LPS® represents a particularly promising educational opportunity. Wickramasekara et al. (2020) explored the potential of combining these domains to enhance the adoption of computer simulation and modelling within the construction industry. The research identifies significant synergies between computer simulation LPS®, and BIM, suggesting that their integration can improve collaboration among construction project stakeholders, enhance understanding and execution of construction plans, and promote effective decision-making.

From a practical implementation perspective, Heigermoser, García de Soto et al. (2019) introduced a prototype BIM-based tool integrating LPS® to improve construction project management. This tool leverages synergies between BIM and Lean Construction to facilitate automated quantity take-off, 4D construction simulations, and systematic evaluation of construction planning. Designed primarily for use during the construction phase, the tool supports short-term planning processes, improving productivity, manpower allocation, and waste reduction. More recent frameworks, such as Lean Construction 5.0, explicitly fuse BIM, IoT, AI, and robotics with Lean tools like the Last Planner System® to enhance workflow reliability and real-time collaboration (Aguilar Zavaleta 2025).

Although BIM and LPS® integration has proven effective in professional practice, its use in educational settings is limited. Existing tools often require substantial technical expertise and may not offer an intuitive, exploratory learning experience for students new to LPS® concepts. This paper introduces a novel approach that combines visual programming (Grasshopper) with 3D/4D simulations to enhance LPS® training. By leveraging parametric design, this method dynamically links spatial and temporal contexts (to observe temporal/completion sequence), providing a more interactive and comprehensive learning

experience than tools that focus solely on BIM or Lean simulations. In doing so, this work expands research on simulation exercises for Lean principles while aligning with the digital skills needed by students and professionals in modern construction management.

Visualization and Simulation for LPS®

This paper examines the effects of incorporating visual programming and simulation (3D objects and time-based simulation) on LPS® case study in the classroom. LPS® is a production planning methodology designed to enhance the reliability and flow of construction projects. The system enhances work environments by prioritizing the assignment of feasible and well-prepared tasks. It integrates collaborative planning and decision-making, focusing on aligning what should, can, and will be done. By systematically managing variability and ensuring that task prerequisites are met, the LPS improves predictability, reduces waste, and fosters more efficient project execution (Ballard and Howell 1994).

While LPS® includes multiple interconnected components, this study focuses specifically on Lookahead Planning (LAP). The authors chose LAP because it is a stage reliant on visualizing both spatial and temporal constraints. In addition, as described by Tommelein and Ballard (1997), LAP bridges the gap between abstract project-level plans and practical task execution, lending itself particularly well to simulation-based teaching.

Traditionally, LPS® implementation relies on sticky notes to (visually) represent tasks and facilitate coordination (Tiwari and Sarathy 2012), allowing teams to plan and sequence activities collaboratively. Sticky notes enable the organization of tasks, timelines, and dependencies, facilitating the visual mapping of tasks and milestones, making it easier to understand the sequence of operations and identify potential conflicts. By laying tasks on a wall or large board, stakeholders can see relationships among trades, ensuring alignment and coordination. The board is a visual representation that serves as a mediating mechanism for team members to interact with. While effective for essential collaboration, using sticky notes as a visual representation method has inherent limitations in scalability and adaptability. Digital visual representation alternatives like digital dashboards (built from popular tools like Lucidchart) have emerged, offering more dynamic visualization capabilities (Faulkner and Contributor 2018). This approach still primarily represents tasks in text-based forms to convey the meaning of relationships among tasks, lacking the ability to leverage spatial and physical context in planning.

While traditional sticky note methods and digital alternatives can support basic visualization tasks, incorporating 3D objects and time-based simulation (4D visualization) provides significant advantages. The importance of 4D visualization in construction lies in its ability to integrate time-related data into 3D models, creating a dynamic representation of the construction process. This enables project managers to visualize the entire construction sequence, from planning to execution, with a clear timeline. This approach allows for visualization of spatial constraints, physical interactions among design elements, and dynamic representation of the construction sequence (Korde et al. 2005).

Methodology

The authors developed an instructional intervention that employed visual programming to support the explanation of Last Planner System® (LPS®) concepts as part of a Lean Construction and Control course. The exercise integrates parametric design principles by linking three-dimensional building elements with time-based planning information through visual programming using Grasshopper. This approach enabled students to interactively explore planning logic by manipulating task durations, buffers, and spatial constraints while immediately observing their implications through four-dimensional (4D) representations.

Rhino and Grasshopper were selected because they provide an open and transparent environment in which planning relationships can be explicitly defined and modified, supporting hands-on exploration and rapid iteration aligned with the learning objectives of the LPS. In contrast, commercial tools such as Navisworks and Synchro are primarily designed for professional 4D coordination and CPM-based scheduling workflows with non-visual programming capabilities. Accordingly, Rhino with Grasshopper was adopted to prioritize instructional clarity, conceptual understanding, and learning experimentation rather than project control or execution. This instructional structuring is consistent with recent construction education research that conceptualizes learning as a progression from instructional features to cognitive and affective learning processes and, ultimately, educational outcomes (e.g. Abbas et al. (2023)), as well as engineering pedagogy studies that employ active and project-based learning environments to support planning, decision-making, and teamwork skills (Almeida Del Savio et al. 2023).

Parametric design refers to an approach in which relationships between model components are governed by parameters and rules rather than fixed geometry (Monedero 2000). When implemented through Grasshopper and Rhino3D, parametric design exposes planning variables, including task durations, start dates, buffers (e.g., weather or material delays), precedence relationships, and space constraints, as editable inputs. Modifications to these parameters automatically update the 4D sequence and visual states (e.g., planned, in progress, completed), allowing students to dynamically simulate and evaluate the effects of their planning decisions. This approach extends beyond static visualization by incorporating dynamic simulation capabilities that support the understanding of temporal and spatial constraints inherent in construction planning tasks. Construction environments are characterized by variable and ill-structured conditions (Jonassen 2011), which place significant cognitive demands on learners to process spatial relationships among resources and building elements, as well as temporal logic governing task sequencing and interdependencies.

Prior research has shown that limited spatial and temporal cognitive ability can hinder students' capacity to interpret and manage local planning conditions effectively (Mutis 2014, Antonenko and Mutis 2017, Mutis 2018). The learners' abilities to effectively manage and comprehend significant amounts of spatial (how design components or resources relate to one another in 3D space) and temporal (the logic in a process, such as the order, sequences, and hierarchies of the resources within a construction task) information are the spatial cognitive ability (Mutis 2017, Mutis 2018). The presented instructional approach addresses these



challenges by allowing students to actively control visualization, simulation, and analysis of construction sequences, task dependencies, and resource allocation within a three-dimensional context. By doing so, it provides cognitive scaffolding that supports spatial-temporal reasoning, motivation, and self-efficacy in planning tasks, consistent with recent perception-based assessment approaches in engineering education (Almeida Del Savio et al. 2023).

Figure 1 illustrates the instructional workflow and conceptual structure implemented during the classroom activity. The exercise was designed using a role-play format to simulate real-world organizational and planning scenarios, enabling students to engage in experiential learning activities consistent with Kolb’s experiential learning theory (Kolb 1984). Within this framework, students assumed different roles (e.g., leaders and team members) to actively engage with Last Planner System® (LPS®) and Look-Ahead Planning (LAP) concepts through 4D visual programming representations. The instructional and representational design supports cognitive and affective learning processes, particularly spatial-temporal reasoning, engagement with planning logic, motivation, and self-efficacy, which subsequently inform the perceptions assessed in this study.

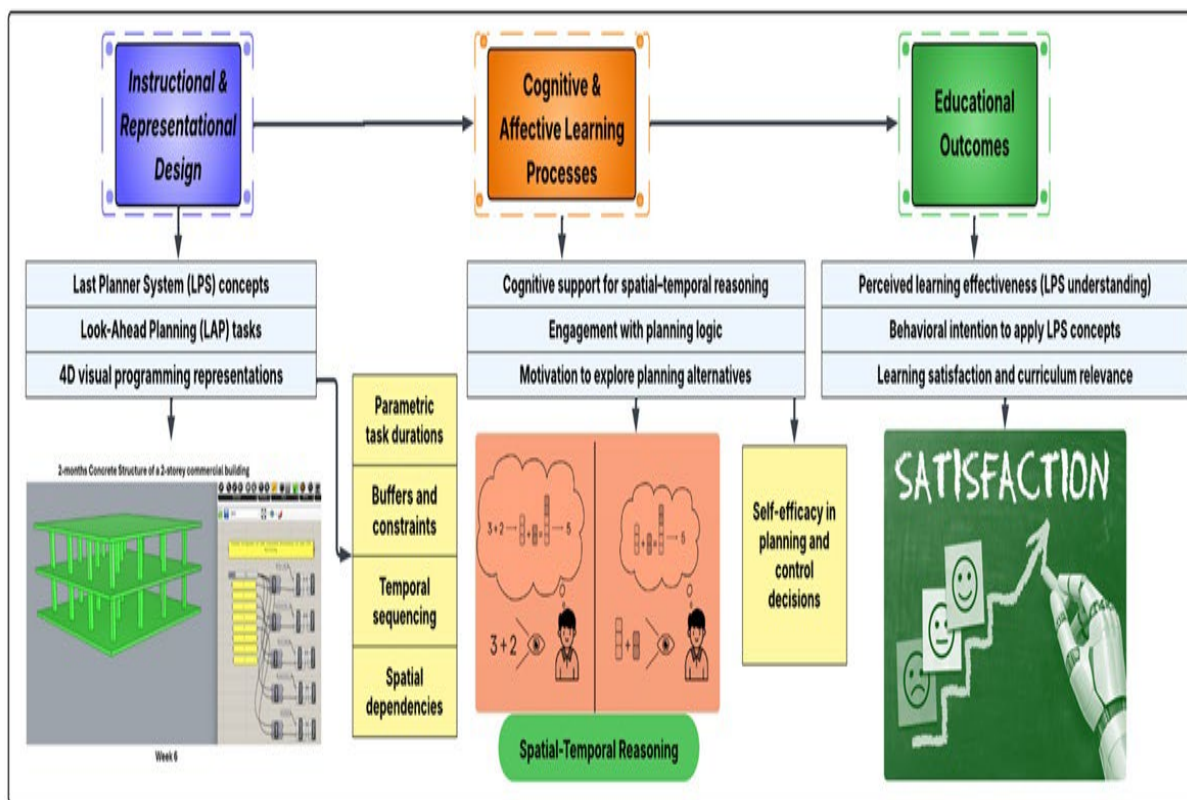


Figure 1: Workflow of LPS Implementation and Survey Development

At the end of the lesson, an anonymous survey was conducted to gather students' perceptions of the visual programming exercise. The survey assessed various dimensions,

including demographics, prior knowledge of visual programming for 4D modeling, engagement, motivation, emotions, usability, knowledge, and curriculum recommendations. Responses were measured using a Likert (1932) scale and usability-oriented items informed by established perceived-usability measurement approaches, including the System Usability Scale (SUS) (Brooke 1996, Lewis 2018). These instruments are widely used psychometric tools for quantifying attitudes and perceptions in educational and social science research (Joshi et al. 2015).

To strengthen the empirical and theoretical grounding of the survey, the questionnaire dimensions were informed by commonly adopted constructs in educational psychology and human-computer interaction research. In particular, the usability dimension reflects perceived usefulness and ease of use, which are central constructs in standardized usability assessment and technology-acceptance research (Brooke 1996, Lewis 2018, Vlachogianni and Tselios 2021). Engagement and motivation, which are key determinants of educational and behavioral outcomes (Bruinsma 2004, Schneider et al. 2016, Collie and Martin 2019), draw on learner engagement and perspectives that emphasize interest, enjoyment, and willingness to continue learning during active instructional activities. Emotional performance captures affective responses that are known to influence learning experiences in the classroom (de Guinea et al. 2014, Darban and Polites 2016, Tan et al. 2021). The knowledge dimension represents perceived understanding and learning relevance rather than objective learning outcomes, consistent with perception-based evaluations commonly used in exploratory classroom studies (Abbas et al. 2023). Finally, the curriculum recommendation dimension reflects perceived instructional value and students' willingness to support integration of the approach into formal coursework. Together, these dimensions provide a theoretically informed yet exploratory framework for examining students' perceptions of the 4D visualization-based learning activity.

Internal consistency and reliability of the survey instrument were evaluated using Cronbach's alpha (α), a widely adopted measure for assessing the coherence of multi-item constructs in social science and educational research (Cronbach 1951, Thorndike 1995, Brown 2002, Tavakol and Dennick 2011). Cronbach's alpha values were calculated at the construct level using item-level responses and are reported together with 95% confidence intervals to reflect estimation uncertainty associated with the moderate sample size. As summarized in Table 2, all constructs exhibited high internal consistency, with α values exceeding the commonly accepted threshold of 0.70 for exploratory educational studies. Although reliability estimates based on small samples should be interpreted with caution, the lower bounds of the confidence intervals remained high across all constructs, indicating stable internal coherence among items. In addition to Cronbach's alpha, McDonald's omega (total) was computed to provide a complementary, factor-based estimate of internal consistency; omega values were highly consistent with alpha across all constructs. Taken together, these results are interpreted as pilot reliability evidence, supporting the use of the instrument for exploratory analysis of students' perceptions rather than as definitive scale validation. This perception-based, multi-construct reliability assessment aligns with contemporary engineering education

research evaluating active and project-based learning environments (Almeida Del Savio et al. 2023).

Table 2: Internal consistency reliability of survey constructs (Cronbach's α) and (McDonald's ω).

Construct	Items	Cronbach's α	α 95% CI	McDonald's ω (total)
Usability	5	0.93	[0.89, 0.96]	0.94
Motivation	4	0.98	[0.96, 0.99]	0.98
Enjoyment	3	0.94	[0.90, 0.97]	0.95
Perceived learning (Knowledge)	5	0.95	[0.93,0.97]	0.96
Curriculum	3	0.97	[0.95,0.98]	0.97
Emotional response	7	0.94	[0.90,0.96]	0.94

In-class exercise deployment

The in-class intervention, consisting of applying the Last Planner System® in a real-world construction planning scenario, was conducted during a single 150-minute class session of the Lean Construction and Control course. The course is part of the core curriculum for the Master of Engineering in Construction Engineering and Management program. Notably, there are no prerequisites for graduate students for the course, and typical students have backgrounds in civil engineering, architectural engineering, and architecture. A good number already have internships and work experience. However, undergraduate students must be in the fifth year of their co-terminal degree program since this class is a graduate-level course. Students take other related courses on construction management before or concurrently with Lean Construction and Control, such as Construction Planning and Scheduling, Equipment Management, Cost Accounting and Control, Contract Administration, and other undergraduate-level courses.

The activity followed a structured sequence consisting of (1) a lecture-based introduction to the principles of the Last Planner System® (LPS®) and Look-Ahead Planning, (2) a guided demonstration of the 4D visual programming environment using Rhino and Grasshopper, (3) a hands-on group exercise, and (4) an anonymous online survey during the final minutes of the class session to reflect on the learning experience. The hands-on group exercise, further detailed below, consisted of a two-step process: first, groups used the sticky note method (traditional method) to develop LAPs, as shown in Figure 2. Once completed, they input their results into the 4D visualization software to observe structural differences

through color changes by adjusting the time slider. This activity provided students with practical experience in collaborative planning, constraint management, and the use of parametric design tools for construction workflow visualization.

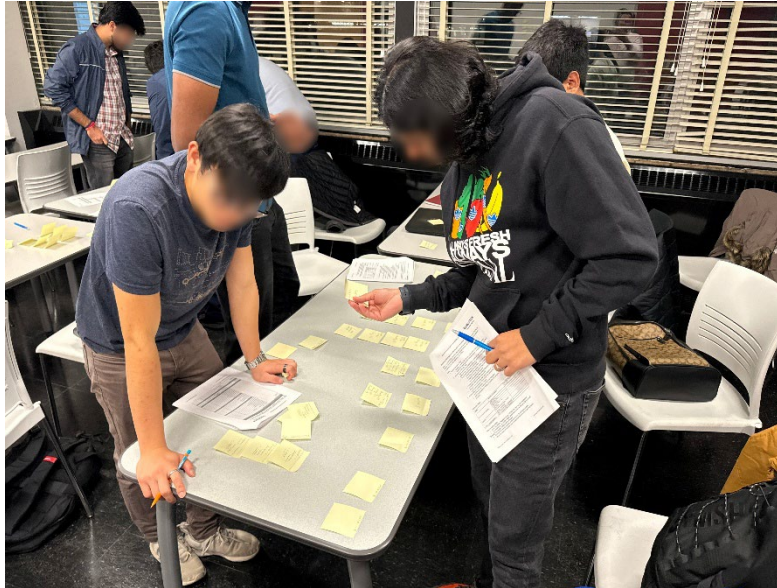


Figure 2: Stakeholders conducting Look-Ahead Plan (LAP)

Students were organized into small groups of three to five members, with each participant assigned a professional role in the hands-on simulation exercise, including Project Manager, General Contractor, and subcontractors representing concrete, masonry, and HVAC trades. The problem statement of the instructional activity was as follows: “You are tasked with developing and validating a Look-Ahead Plan (LAP) for the concrete structure of a two-story commercial building using Last Planner System® (LPS®) principles. The planning problem required teams to sequence and coordinate interdependent activities, such as excavation, rebar installation, formwork, concrete pouring, elevator core masonry (treated as an independent structure), and HVAC conduit installation, while accounting for concurrency, inspections, curing times, constraints, and buffers. You are provided with a master plan containing task durations and subcontractor scopes and were instructed to collaboratively assess the feasibility of the proposed schedule. Additional constraints, including material delivery delays and anticipated weather disruptions, were introduced to require proactive constraint management. The construction sequence progressed from excavation and foundation work to slabs, columns, and the roof, with a hypothetical project start date of December 1, 2024. The planning task was first completed using traditional visual methods (e.g., sticky notes) and then translated into a 4D visualization environment using Grasshopper and Rhino to simulate construction progress over time.”

The exercise had the following three key phases, each progressively integrating planning, visualization, and digital tools.

- 1) Reviewing the Master Plan: Stakeholders held a collaborative meeting to review the provided master plan, evaluate the feasibility of task timelines, and identify constraints such as material delays and weather disruptions (see Figure 3).
- 2) Developing a Look-Ahead Plan (LAP): Groups created an eight-week LAP, incorporating buffers to address identified constraints, such as a 4-day delay in critical materials and 2 days of anticipated rain. The plan was visualized using the traditional method of sticky notes.



Figure 3. Stakeholders reviewing the master plan and building the LPS®

- 3) 4D Simulation with Grasshopper and Rhino: Following the manual planning phase, groups input their revised timelines into a 4D simulation to validate their logic, as shown in Figure 4.



Figure 4. Students using the 4D Visualization tool

To facilitate this, students worked within a pre-structured Grasshopper script provided by the instructor that divided the construction process into clear phases, such as Slab Pouring, Column Casting, and Wall Installation. Students digitized their manual plans by inputting start and duration values by typing them into the text field of the Grasshopper canvas as shown in Figure 5.

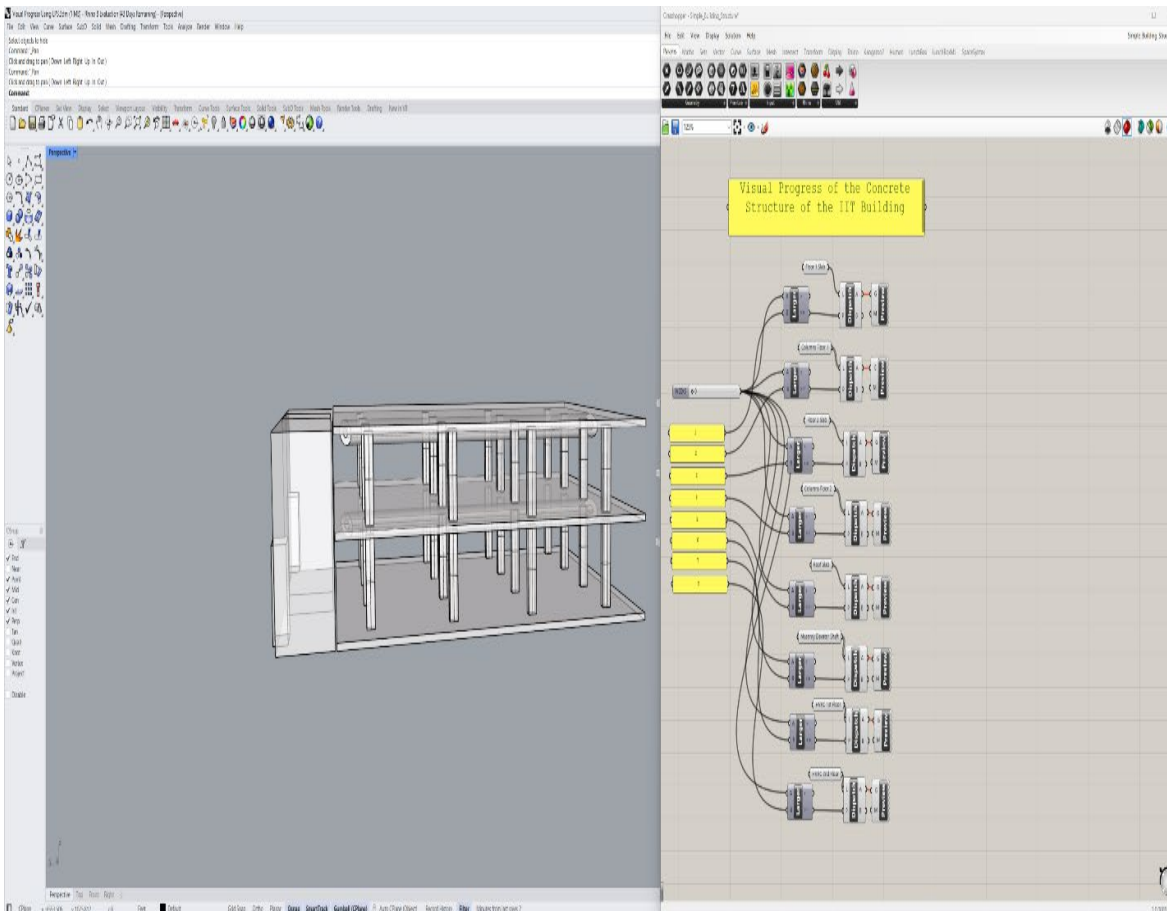


Figure 5: Rhino and Grasshopper for Visualizing LPS on the initial stage

A week-by-week timeline visualization was created using a slider, allowing users to update and view the progress of tasks against the project schedule. Color coding was automatically implemented to differentiate task statuses (grey for planned, yellow for in progress, and green for completed) providing an intuitive understanding of project milestones. Additionally, the software allowed toggling the visibility of building elements like slabs and columns, reflecting their construction status dynamically. These features constituted a new way of representing planning tasks for the group members (project stakeholders) and provided an efficient, visually clear method for monitoring construction projects. Figure 6 illustrates the progress of the building and the completed tasks in week 6, as outlined in the Look-Ahead plan (LAP) prepared by stakeholders.

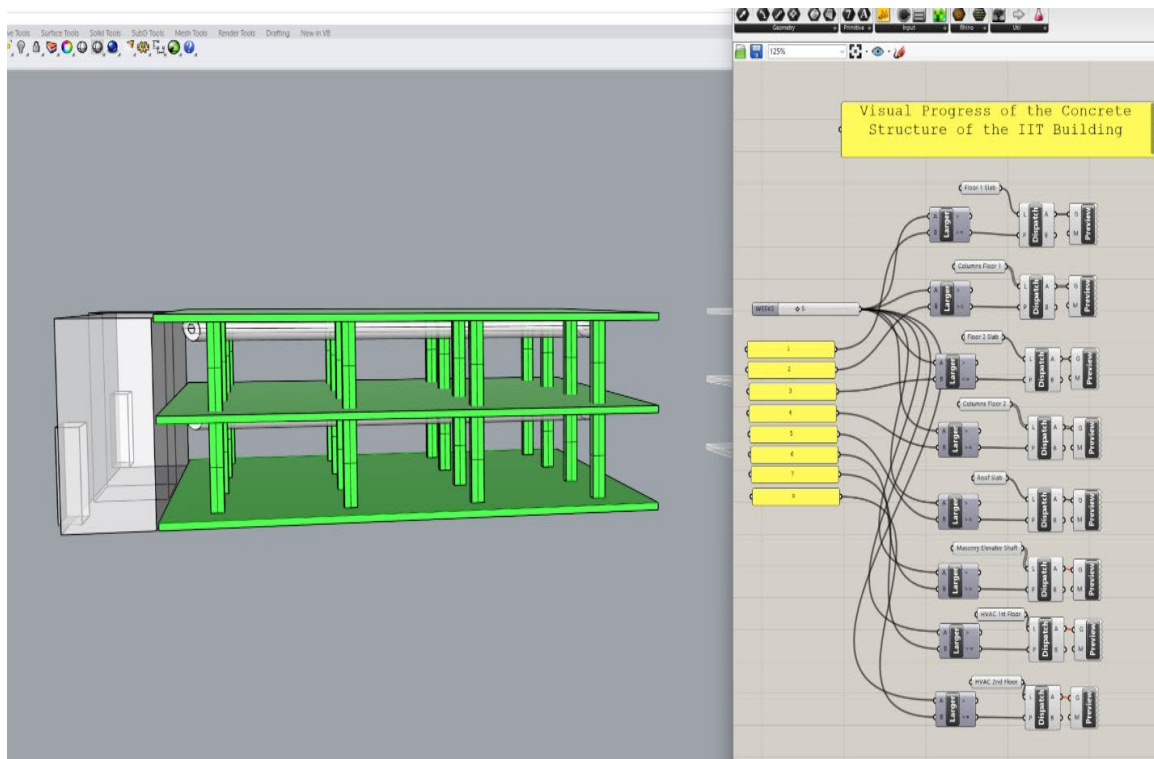


Figure 6. Rhino and Grasshopper for Visualizing LPS on Week 6

Results and Analysis

Survey responses from 37 participants were analyzed across the six dimensions defined in the methodology. The analysis focuses on students' self-reported evaluations to assess the reception and perceived utility of the instructional approach. Accordingly, the findings presented below characterize the learner experience and engagement with the tool, rather than providing objective measures of skill acquisition or professional practice outcomes.

In terms of gender, 21% of participants were female and 79% were male; the age range was 20 to 30 years. The unbalanced sample across gender is a common trend in Construction Management programs, where female students are severely underrepresented (Sewalk and Nietfeld 2013, Bigelow et al. 2015). For instance, only 10% of Construction Managers in the United States are estimated to be women (Coskun et al. 2024). Because of the small number of female students, the authors were unable to analyze gender-based results. However, the five female students rate the exercise as positively as the male students do.

Most respondents (87%) had a graduate-level education, while 13% were pursuing co-terminal undergraduate studies. When asked about their experience in construction management, 62% reported prior construction experience, while 38% did not. Subsequent questions focused on participants' prior knowledge of visual programming for 4D modeling. A total of 51% had experience with parametric design software, while the majority (76%) had

used computer simulation software. Additionally, when asked about their experience with visual programming, 46% responded positively, as illustrated in Figure 7.

As shown, the sample is more balanced across groups by experience, particularly in construction management and in more specific tools such as parametric design software and visual programming. This allowed the authors to perform subgroup analysis across levels of experience, which is presented in the Statistical Analysis section below.

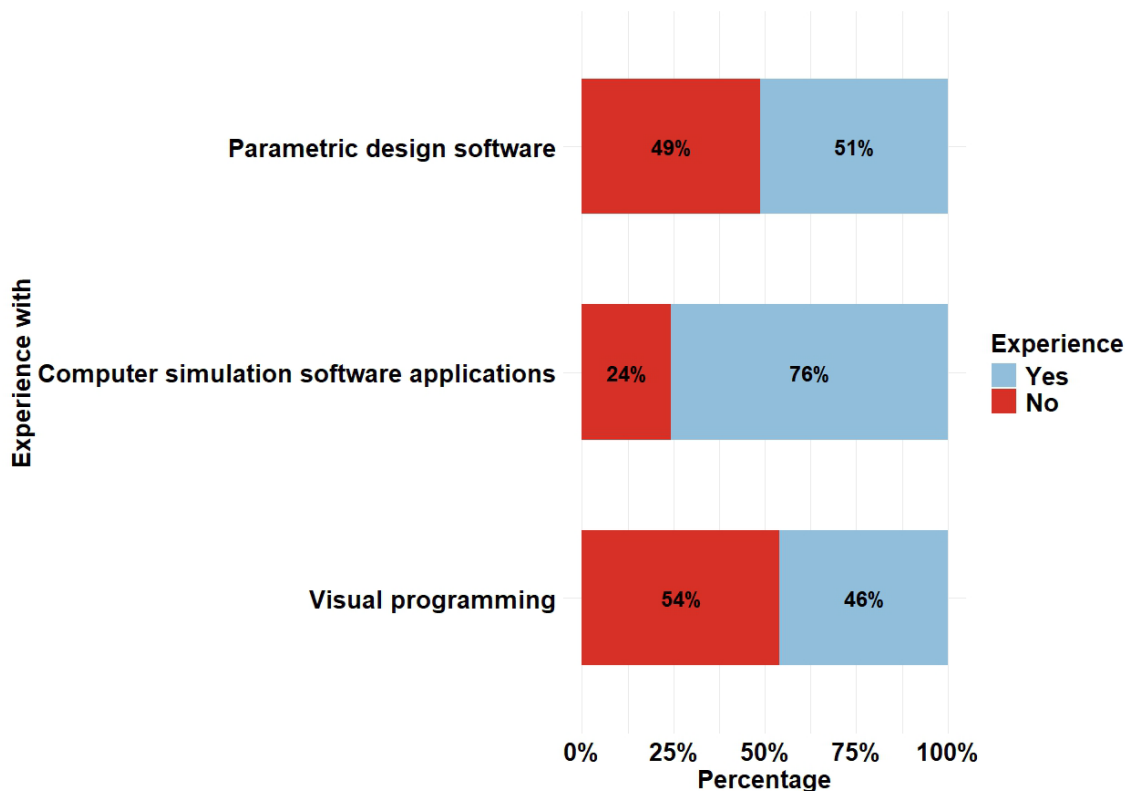


Figure 7. Previous Knowledge of Tools

Engagement

Following established definitions of engagement, which include attributes including “motivation, interest, and affect” (O’Brien and Toms 2008) student engagement with the new tool was measured using several questions that assessed their enjoyment and motivation while using it, as well as other emotions, both positive and negative. First, as seen in Figure 8, the class exercise with 4DS (BIM 4D Simulation) proved enjoyable for most students (over 79% found it fun.

and pleasant). Importantly, this sense of enjoyment translated to high levels of motivation to continue improving simulation and modelling skills. As illustrated in Figure 9, most of the class responded very positively to all motivation questions.

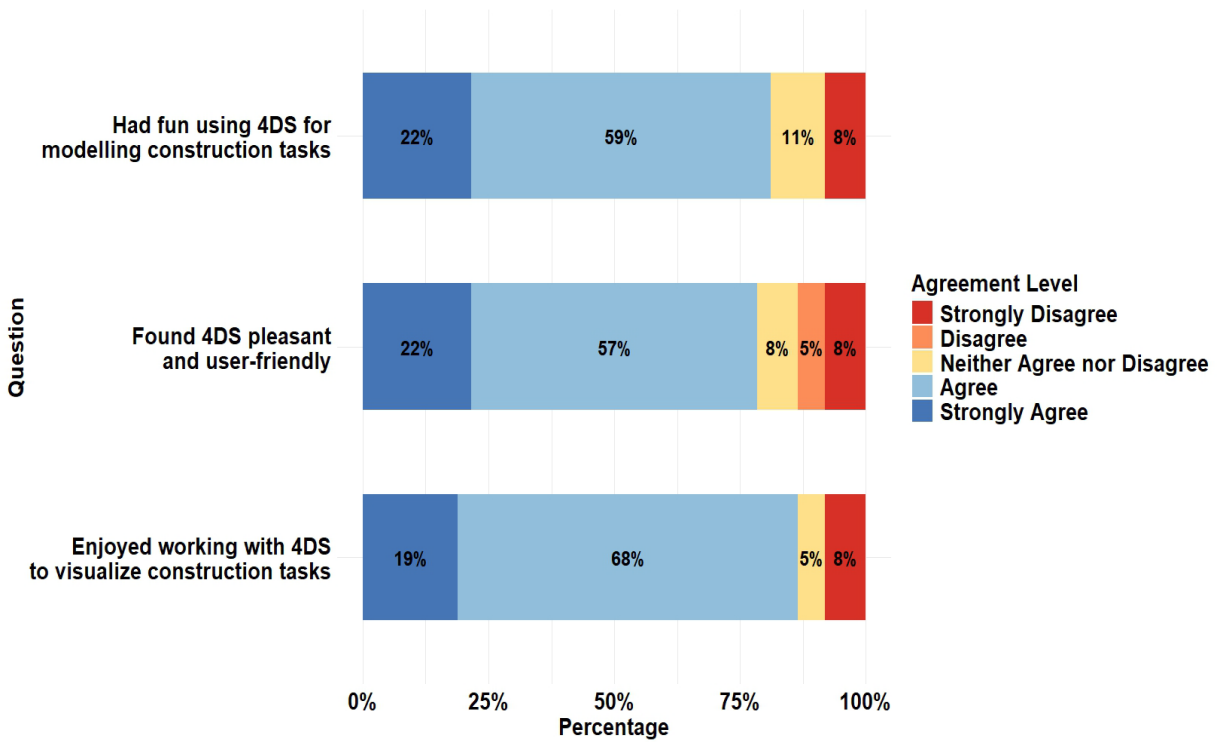


Figure 8. Enjoyment levels

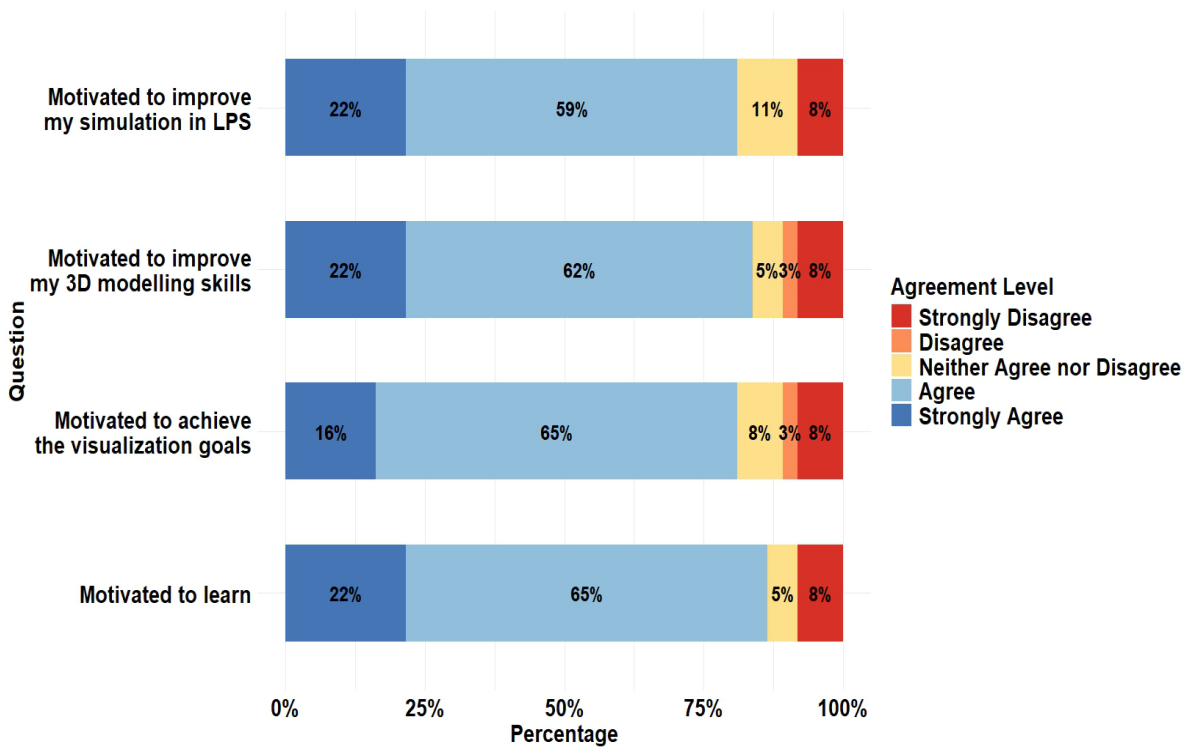


Figure 9. Motivation levels

Following previous work on the importance of emotions in determining use intentions and adoption of new tools (e.g. de Guinea et al. 2014, Darban and Polites 2016), the survey asked respondents to report more specific positive and negative feelings experienced throughout the process (Figure 10). Coinciding with the high levels of enjoyment shown above, around 70% of students were at least in agreement (if not in strong agreement), feeling happy, confident and enthusiastic during the exercise. On the negative side, 52% of students reported feeling worried about making mistakes, leading to 55% experiencing nervousness at some point during the process.

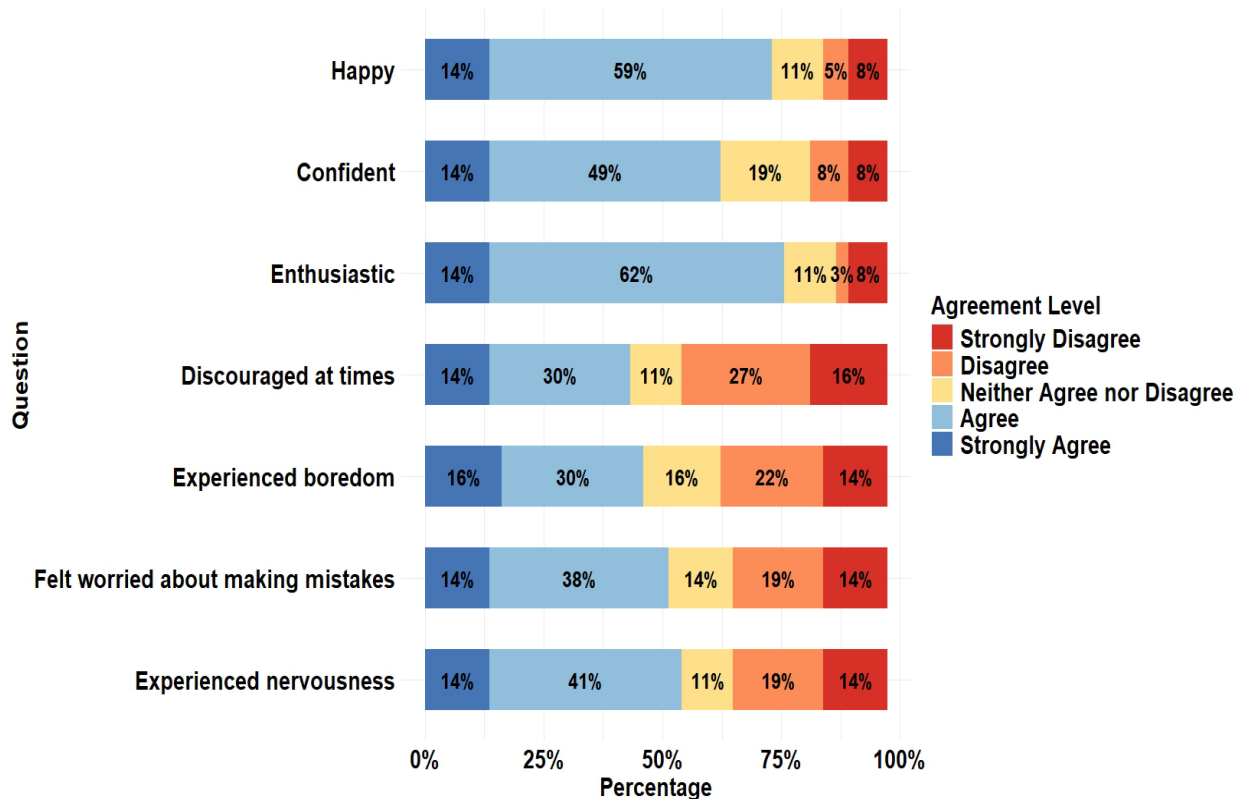


Figure 10. Emotional performance

Practicality and Learning

Participants not only reported high levels of enjoyment and motivation when using the 4D tool but also perceived the approach as useful and supportive of their understanding of planning concepts. In terms of usability, a key determinant of educational effectiveness and technology adoption (e.g. Vlachogianni and Tselios 2021), the percentage of students who think simulating 4D is useful, faster than traditional methods, and easier ranged from 63% to 78%. Over 80% of students also appreciate the tool's ability to coordinate tasks and visualize conflicts and workflows as shown in Figure 11.

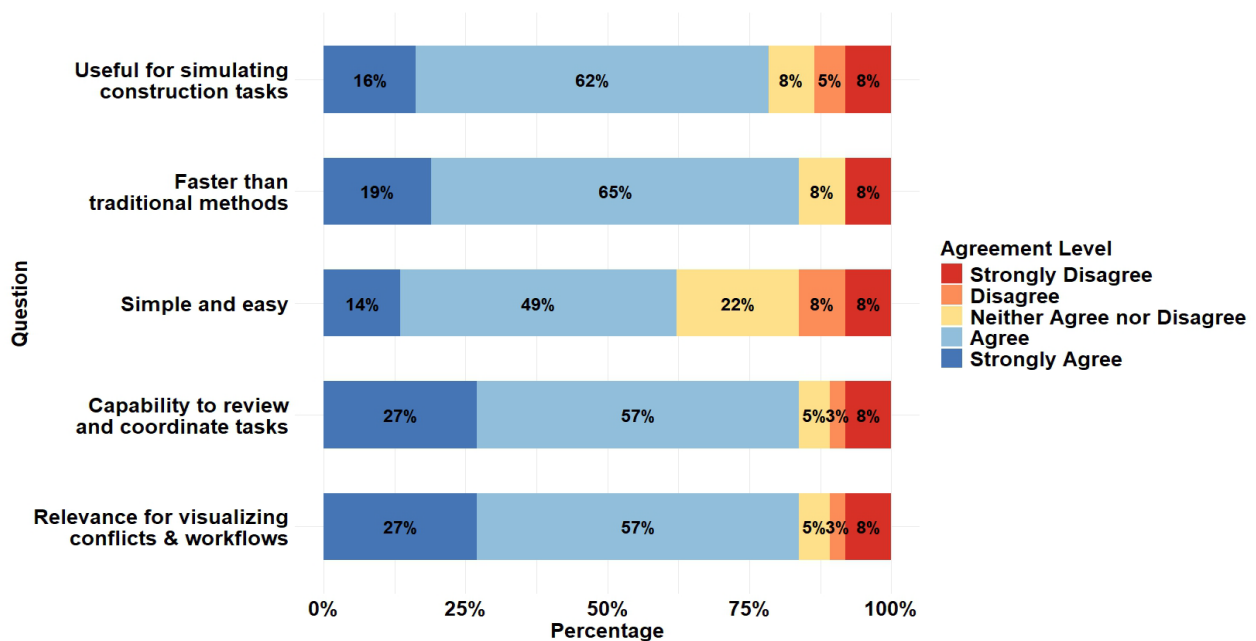


Figure 11. Perceptions of usability

In addition to perceiving the usefulness of the 4DS simulation tool, the survey asked students whether the tool contributed to their learning (e.g. Abbas, Seo et al. 2023). Results show that students claim to have gained relevant knowledge during the exercise. For most items evaluated, such as whether the exercise helped with understanding task visualization and conflict identification, close to 85% of students agreed reflected in Figure 12.

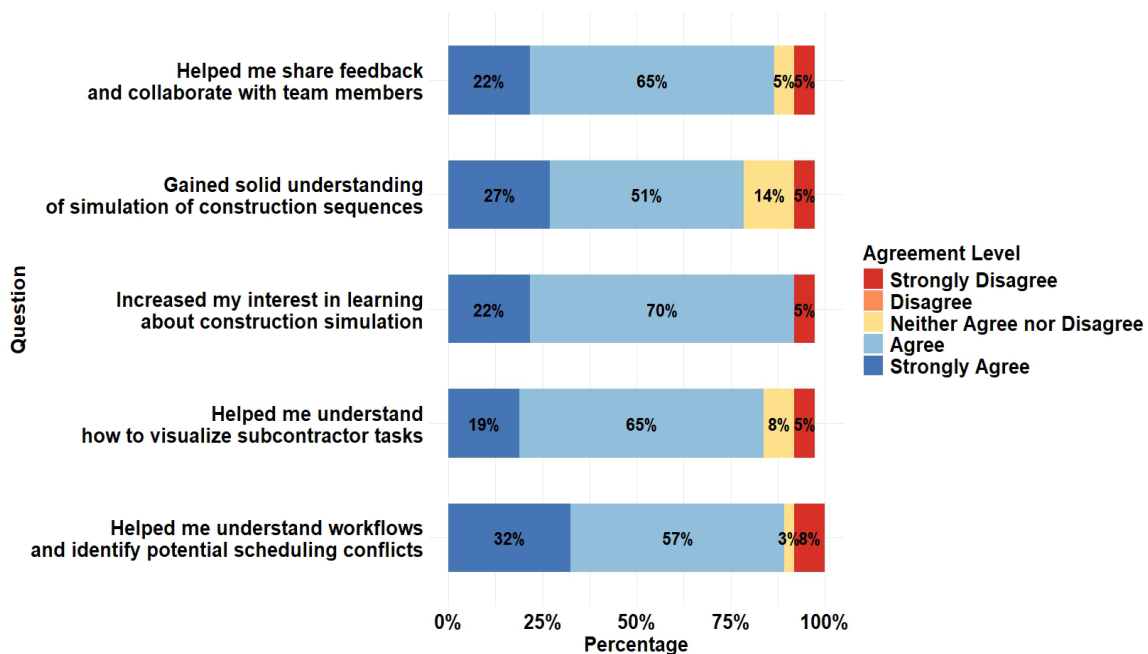


Figure 12. Perceived learning (knowledge)

The survey also collected students' recommendations for incorporating this tool into the Lean Construction curriculum. Figure 13 illustrates overwhelming student interest in incorporating 4D simulation tools into the course, highlighting their potential to replace or complement traditional methods. In addition, over 85% of participants view 4DS as a beneficial skill beyond the classroom. The observed positive feedback across these dimensions is key since many students enroll in this master's with the hope of learning new tools that will be useful in the job market. Having experience with more novel alternatives to traditional methods will make them more competitive candidates.

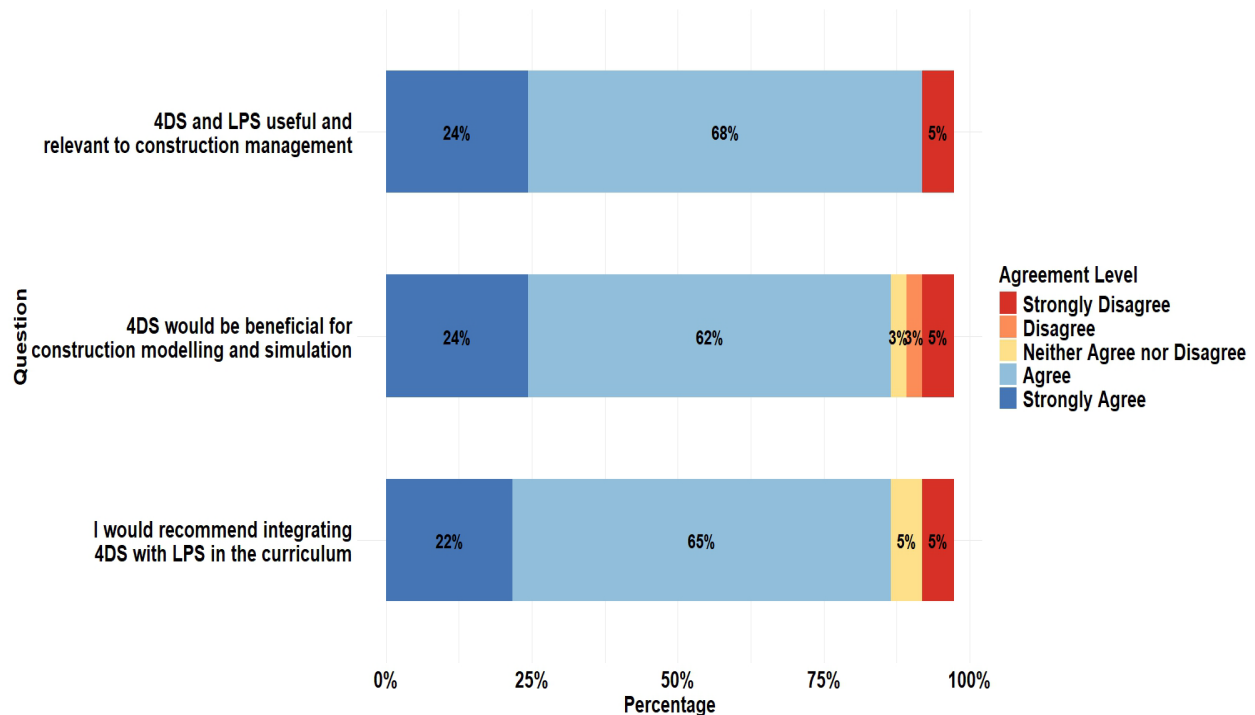


Figure 13. Perceptions of curriculum relevance

Statistical Analysis

In this section, the authors provide an overview of the scores across survey dimensions and conduct exploratory statistical comparisons of student evaluations across different experience levels, emphasizing descriptive patterns and the direction of differences rather than definitive hypothesis testing.

Figure 14 summarizes the scores for all questions within each survey dimension, providing a quick comparison of how students evaluated the simulation exercise. Recall that each question was asked on a Likert scale from 1 to 5, so values closer to 5 indicate full agreement or satisfaction with that aspect of the simulation. The 'Emotions' dimension was excluded from the summary index, as averaging positive and negative emotions together would obscure meaningful patterns. As shown in the analysis of the individual questions above, this figure reinforces the fact that students were highly satisfied with the exercise. Among all

dimensions, the highest scores were for questions asking whether this new tool should be incorporated into the curriculum (4.03) and whether the tool helped understand the concepts learned in the lecture (4.01). The lowest level is in the “Usability” dimension, referring to whether students view this 4D as useful in identifying conflicts and its ease of use, though it is still a high average (3.79).

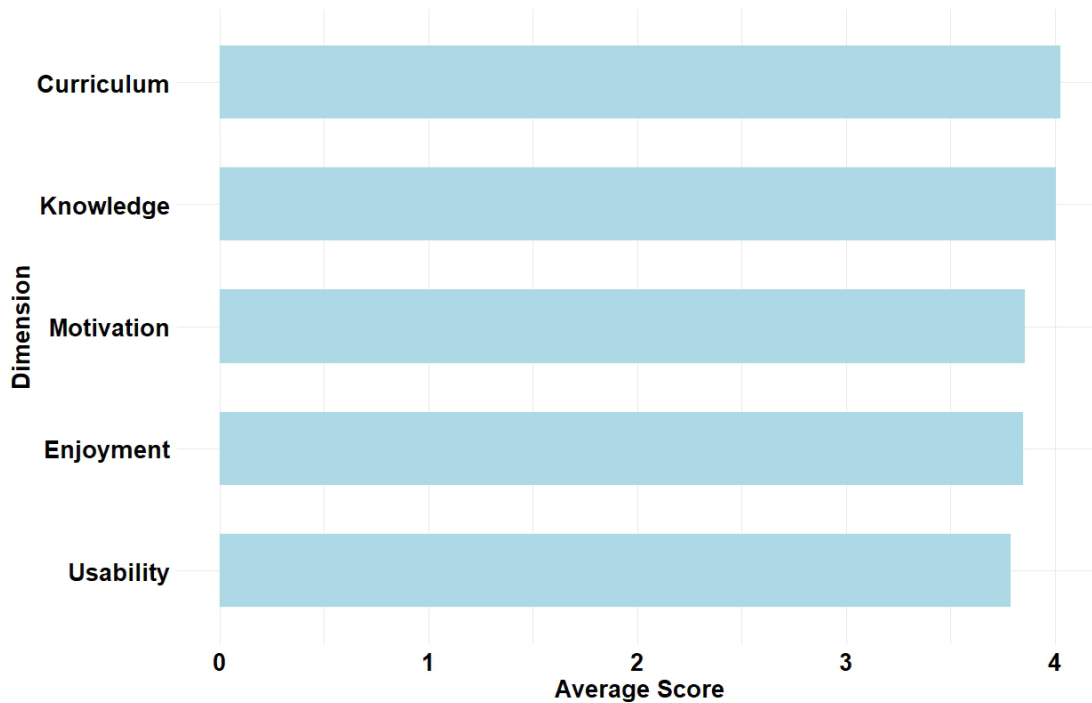


Figure 14: Summary index of each dimension

Table 3 presents summary statistics for each dimension, including the mean, median, standard deviation, minimum, and maximum. Complementing the mean with the median and standard deviation shows that high levels of evaluation of curriculum and knowledge, for instance, are not driven solely by a few outliers. Most students’ evaluations are tightly clustered around 4.

Table 3: Summary of Statistics

	Mean	Median	SD	Min	Max
Usability	3.79	4.00	0.95	1.00	5.00
Motivation	3.86	4.00	1.00	1.00	5.00
Enjoyment	3.85	4.00	0.99	1.00	5.00
Knowledge	4.01	4.00	0.86	1.00	5.00
Curriculum	4.03	4.00	0.88	1.00	5.00

In the following tables, the authors compare overall evaluations across levels of experience with visual programming tools, parametric design software, and construction management. Given the exploratory nature of this study and the moderate sample size (N=37), the authors present these comparisons primarily to identify descriptive patterns and potential disparities in student engagement, rather than to derive definitive statistical inferences. The p-values provided in the tables (resulting from both t-tests and Wilcoxon tests, which are more robust for small sample sizes) are included for completeness but should be interpreted with caution; the primary focus of this analysis is on the magnitude of the differences between groups to assess whether the intervention was equally accessible to students of varying backgrounds.

Table 4 compares those with and without experience with visual programming tools. Those with some experience tend to evaluate the exercise higher across all dimensions. The data reveals a consistent descriptive trend: students with prior experience rated the exercise higher across all dimensions. However, the magnitude of these differences varies. For example, the gap in Usability (0.32) and Enjoyment (0.39) suggests that familiarity with the interface may smooth the initial learning curve. Conversely, the difference in Motivation (0.21) is smaller, implying that the task remained engaging even for those navigating the technical challenges for the first time. While statistical tests do not detect significant differences, the consistently positive direction suggests that prior technical exposure may offer a slight initial advantage in comfort level.

Table 4: Comparing average evaluation for each dimension according to experience with Visual Programming

Dimension	Experience	No Experience	Difference	p-value(t-test)	p-value (Wilcoxon)
Usability index	3.96	3.64	0.32	0.31	0.07
Motivation index	3.97	3.76	0.21	0.53	0.49
Enjoyment index	4.06	3.67	0.39	0.24	0.11
Knowledge index	4.13	3.89	0.23	0.43	0.31
Curriculum index	4.20	3.88	0.32	0.29	0.13

Table 5 compares individuals with and without experience in parametric design software. Here, the differences between groups are remarkably small, indicating a high level of parity. For the Usability dimension, the difference is negligible (0.02), suggesting that the providing students with a ready-to-run script successfully neutralized the advantage typically held by experienced users. A notable inversion appears in the Knowledge dimension, where students without prior experience rated the exercise higher (4.10) than their experienced peers (3.91). While not a statistically significant difference, this pattern descriptively supports the pedagogical goal: the tool appears to offer the greatest perceived learning value to those with the least prior exposure to the technology.

Table 5: Comparison of Evaluation According to Experience with Parametric Design Software.

Dimension	Experience	No Experience	Difference	p-value(t-test)	p-value (Wilcoxon)
Usability index	3.80	3.78	0.02	0.94	0.31
Motivation index	3.83	3.89	-0.06	0.86	0.67
Enjoyment index	3.91	3.78	0.13	0.68	0.26
Knowledge index	3.91	4.10	-0.19	0.52	0.99
Curriculum index	4.06	4.00	0.06	0.85	0.08

Finally, the authors compare evaluations of the simulation task between students with and without experience in the construction management industry, as shown in Table 6. Contrary to the expectation that industry experience might dictate perceived utility, the data shows virtually no difference between the groups. In fact, novices reported slightly higher scores in Usability and Motivation, though the differences are practically insignificant (< 0.15). This consistent distribution of evaluation scores is a critical finding for the intervention's design. It suggests the tool is agnostic to student background: the lack of substantial differences implies the activity was robust enough to support beginners without alienating experienced professionals.

Table 6: Comparison of Evaluation According to Experience with Construction Management

Dimension	Experience	No Experience	Difference	p-value(t-test)	p-value (Wilcoxon)
Usability index	3.77	3.83	-0.06	0.84	0.96
Motivation index	3.82	3.93	-0.11	0.74	0.92
Enjoyment index	3.80	3.93	-0.13	0.69	0.54
Knowledge index	4.07	3.90	0.17	0.57	0.41
Curriculum index	4.06	3.98	0.08	0.79	0.96

Overall, while the sample size limits the power to detect small effects, the descriptive analysis points to an intervention that is broadly accessible. The differences in mean scores are generally small (often < 0.3 on a 5-point scale), supporting the interpretation that the intervention supports equitable engagement across students regardless of prior technical or industry background. In addition, these findings should be interpreted as reflecting students' perceptions and self-reported evaluations of the instructional approach rather than objective measures of learning performance or skill acquisition.

Conclusions and Future Work

This study introduces a novel approach to teaching the Last Planner System (LPS) by incorporating visual programming and 4D simulation into classroom instruction. Moving beyond the traditional reliance on sticky notes or text-based digital dashboards, this method leverages advanced visualization tools to link tasks with spatial and temporal contexts, making collaborative planning more concrete and dynamic. The approach was implemented in a Lean Construction and Control course, where students created look-ahead plans using both sticky notes and the 4D visualization tool. Survey results indicate that students responded positively to this innovation, finding it engaging, practical, and useful for real-world applications such as tracking progress and visualizing scheduling conflicts. Overall, these findings indicate a high willingness to use this tool in the curriculum.

Importantly, positive perceptions were consistent across students regardless of their prior experience with visualization tools, parametric design software, or construction management. Even those exposed to simulation in Grasshopper for the first time recognized its potential to enhance planning processes. This lack of disparity suggests that the intervention is independent of experience: sufficiently scaffolded to be accessible to beginners while remaining valuable for learners with advanced technical backgrounds.

Beyond its educational context, this study suggests that advanced visualization techniques may offer a promising direction for supporting the teaching and conceptual understanding of LPS-related planning principles. By making dependencies, constraints, and project sequences more explicit in a learning environment, 4D visualization can help students reason about collaborative planning processes in ways that align with industry practices. For educators, the approach illustrates how integrating emerging digital tools into pedagogy can modernize construction management education and better prepare students for professional practice. More broadly, embedding these tools in curricula can help bridge the persistent gap between academic training and industry expectations, ensuring that graduates enter the workforce with skills directly applicable to digitally enabled project delivery.

At the same time, this study has limitations. The small sample size constrains the generalizability of the findings. Furthermore, as this study relies on self-reported perceptions, it does not provide direct evidence of improved learning performance or industry-level operational outcomes. Future research should expand the sample size to enhance statistical power, while also designing experiments to assess learning more explicitly. For example, larger classes could be divided into groups using traditional sticky notes versus 4D visualization, with outcomes assessed to determine whether the novel method improves objective understanding of LPS concepts.

Taken together, this study indicates that integrating 4D visualization into LPS instruction has potential as an educational innovation with relevance beyond the classroom. It provides a pathway to create more engaging, practice-focused learning environments. For industry-oriented education, the study highlights how digital simulations can be used pedagogically to illustrate Lean principles and planning logic in a controlled learning environment. As construction projects increasingly adopt digital technologies, aligning education with these



advancements will be essential to ensure the next generation of professionals can fully embrace the collaborative potential.

"This study was approved by the Institutional Review Board at Illinois Institute of Technology (Protocol #IRB-2026-37). All participants provided informed consent before their involvement."

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Appendix: Survey Questionnaire

Introduction

Please answer the questions about your experience using the Visual Programming software 4DS to visualize the Last Planner System.

1. Demographics

Gender

Male

Female

Non-binary / third gender

Prefer not to say

Age (open response)

Current academic level

Undergraduate student

Graduate student

Construction background

I have work experience in construction management.

I do not have work experience in construction management.

2. Previous Knowledge of Visual Programming for 4D Modeling

I had used a visual programming tool prior to the lecture and exercise. (Yes/No)

I had used computer simulation software prior to the lecture and exercise. (Yes/No)

I had used parametric design software prior to the lecture and exercise. (Yes/No)

3. Satisfaction

Scale: 1 = Strongly disagree, 5 = Strongly agree

I was satisfied with the 4DS instructions.

I was pleased with the new computational method learned in the Last Planner System.

I was satisfied with the relevance of using 4DS to visualize and assess conflicts and simulate workflows.

I was pleased with 4DS capabilities to review and coordinate tasks.

I was pleased with the 4DS method for helping me understand workflows and scheduling conflicts.

4. Usability



Scale: 1 = Strongly disagree, 5 = Strongly agree

The 4DS software is simple and easy to use.

4DS allowed me to simulate and visualize workflows faster than traditional methods (e.g., sticky notes, kanban).

I found 4DS useful for simulating tasks and identifying conflicts.

5. Motivation

Scale: 1 = Strongly disagree, 5 = Strongly agree

I was motivated to learn 4D simulations using visual programming.

I was driven to achieve visualization goals with 4DS.

This learning experience motivated me to improve my 3D modeling skills.

This learning experience motivated me to improve my Last Planner System simulations.

6. Enjoyment

Scale: 1 = Strongly disagree, 5 = Strongly agree

I enjoyed working with 4DS to visualize workflows.

I found the 4DS environment pleasant and user-friendly.

I had fun using 4DS for construction, modeling, planning, and coordination.

7. Knowledge Learning

Scale: 1 = Strongly disagree, 5 = Strongly agree

Using 4DS helped me understand how to coordinate subcontractors' tasks.

I am more interested in learning about construction simulation techniques after using 4DS.

I gained a solid understanding of construction sequencing with 4DS.

4DS helped me share feedback and collaborate effectively with subcontractors.

8. Curriculum Recommendation

Scale: 1 = Strongly disagree, 5 = Strongly agree

I would recommend integrating 4DS with the Last Planner System into the curriculum.

Learning 4DS as part of the curriculum would be beneficial for future construction modeling.

The 4DS and LPS combination is useful and relevant to practice.

9. Emotional Performance

Scale: 1 = Strongly disagree, 5 = Strongly agree



- I experienced nervousness while using 4DS.
- I worried about making mistakes while using 4DS.
- I experienced boredom while working with 4DS.
- I felt discouraged at times while learning 4DS.
- I felt enthusiastic about using 4DS.
- I felt confident while working with 4DS.
- I felt happy when using 4DS to simulate tasks.