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Teaching *Takt*-Time, Flowline, and Point-to-Point Precedence Relations: A Peruvian Case Study

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Abstract

Over the last few years, Point-to-Point Precedence Relations (PTPPR) has emerged as a significant theme in the construction industry, indicating that point-to-point relations are better than Critical Path Method (CPM), both theoretically and practically. As the same time, research has focused on *takt*-time and flowlines. Both methods have been compared and integrated. This article presents strategies for teaching the integration of these popular methods in construction-management courses to undergraduate students of civil engineering at the Pontifical Catholic University of Peru. The case study is a community-house project that has highly repetitive processes in the structural works phase. First, we used traditional tools such as Excel spreadsheets and 2D drawings to teach production-system design with *takt*-time, flowlines, and PTPPR. Second, we used 3D and 4D models with Revit and Navisworks to integrate the previous *takt*-time schedule with a BIM model and identify its strengths and weaknesses. Finally, we used Vico Office for the automation of schedules and comparison of the methods in 4D and 5D. The article describes the lectures, workshops, and simulations employed, as well as feedback from students and instructors. The success of this teaching strategy is reflected in the survey responses from students and the opportunities for improvement identified.

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Keywords: BIM; flowline; point-to-point precedence relations; *takt*-time; teaching.

1. Introduction

Construction projects need a comprehensive production system to improve flow operations in the field, one that goes beyond traditional methods such as the Critical Path Method (CPM). CPM damages the flows in construction

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and, consequently, generates a great deal of waste in the construction process [1]. Moreover, locations are a resource that must be explicitly modeled in all the planning and scheduling methods [2]. *Takt*-time, flowline, and Point-to-Point Precedence Relation (PTPPR) are alternative scheduling methods in the construction management arena [3]. These scheduling methods have been found to be compatible with the different tools, techniques, and methods in project management [4]. In the Peruvian context, some construction companies implement Last Planner System (LPS) and *takt-time* with residential buildings [5]. The purpose of this paper is to present strategies for teaching the integration of these common methods into construction management. Such integration is very much of the moment, in both public and private projects [6]. The research strategy we will use is the case study.

Nomenclature

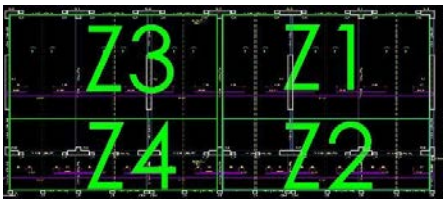
BIM	Building Information Modelling	LSM	Linear Scheduling Method
CPM	Critical Path Method	MEP	Mechanical, electrical, and plumbing
LBMS	Location Based Management System	PDM	Precedence Diagram Method
LOB	Line-of-Balance	PTPPR	Point-to-Point Precedence Relations
LPS	Last Planner System	VPM	Vertical Production Method

2. *Takt*-Time, Flowline, and Point-to-Point Precedence Relations

2.1. Takt-*Time*

"*Takt*" is a German word that refers to the regularity with which something gets done [7]. "*Takt*-time is the unit of time in which a product must be produced (supply rate) in order to match the rate at which that product is needed (demand rate)" [8]. In the manufacturing industry *takt*-time could be in seconds, minutes, hours, days, or weeks. However, the construction industry is different, and its *takt*-times could be defined in hours, days, or weeks. The amount of resources in the desired constant flow must be calculated, to make sure that flow can occur in the selected *takt-time*. In Latin American countries like Peru, the *takt*-time planning is referred to as "activity trains." On projects working under the Lean Construction philosophy, the activity trains (constant production flow) are designed using zones in which daily activities will be executed (one-day *takt*). Figure 1 shows an example of the scheduling of a structure phase that employs a one-day *takt*-time, as expressed in an Excel spreadsheet.

a



b

TASKS	Mon	Tue	Wed	Thu	Fri
	Oct 26	Oct 27	Oct 28	Oct 29	Oct 30
STRUCTURING PHASE	TAKT-TIME / ZONE				
VERTICAL REBAR	Z1-S1	Z2-S1	Z3-S1	Z4-S1	Z1-S2
VERTICAL PIPING INSTALLATION	Z1-S1	Z2-S1	Z3-S1	Z4-S1	Z1-S2
VERTICAL ELECTRICAL INSTALLATION	Z1-S1	Z2-S1	Z3-S1	Z4-S1	Z1-S2
VERTICAL FORMWORK	Z1-S1	Z2-S1	Z3-S1	Z4-S1	Z1-S2
VERTICAL CONCRETE POURING	Z1-S1	Z2-S1	Z3-S1	Z4-S1	Z1-S2
HORIZONTAL FORMWORK		Z1-S1	Z2-S1	Z3-S1	Z4-S1
HORIZONTAL REBAR		Z1-S1	Z2-S1	Z3-S1	Z4-S1
HORIZONTAL PIPING INSTALLATION			Z1-S1	Z2-S1	Z3-S1
HORIZONTAL ELECTRICAL INSTALLATION			Z1-S1	Z2-S1	Z3-S1
HORIZONTAL CONCRETE POURING				Z1-S1	Z2-S1

Fig. 1. (a) Sectorization; (b) *Takt-Time* Schedule of Structural Work.

2.2. Flowline

Linear project scheduling always represents a major challenge to project managers [9]. The Linear Scheduling Method (LSM) is typically used to schedule horizontal repetitive projects, while the Vertical Production Method (VPM) is adopted to schedule vertical repetitive projects [9]. The Line-of-Balance (LOB) method can be used for any type of repetitive projects [10]. LOB is a graphic scheduling method which considers location explicitly as a dimension [11]. Location Based Management System (LBMS) is primarily a technical system that optimizes work continuity based on quantity and productivity information and forecasts future performance. LBMS uses flowlines, not lines of balance [12, 13]. Last Planner System (LPS) is a production-planning system designed to produce

predictable work flow and rapid learning in programming, design, construction, and commissioning of projects [14]. LPS and LBMS are complementary [13, 15].

The flowline scheduling method can be applied in a building of highly repetitive processes. The flowline of each alternative facilitates the comprehension of hand-offs and milestones [16]. However, there might be differences between the planned flowlines and the actual execution curve [3]. To make the flowlines, the planner must divide the project on location into three different levels. First, the location units are divided by story (level 1); second, by daily zones (level 2); and third, by subsectors or production units that are executed during the workday (level 3) [3]. An example of a flowline scheduling for a building with highly repetitive processes is shown in Figure 2.

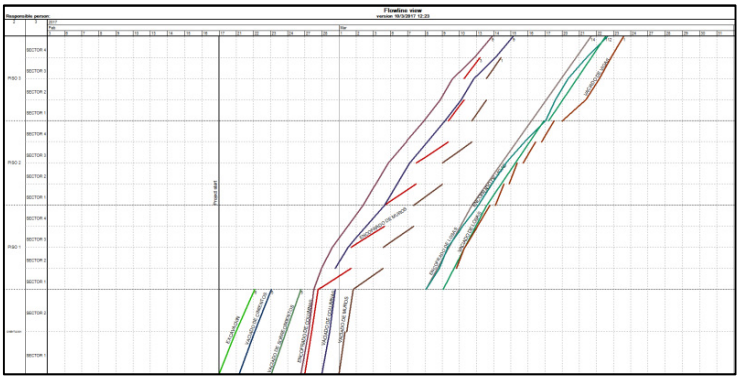


Fig. 2. Flowline Scheduling Developed in Vico Office.

2.3. Point-to-Point Precedence Relations (PTPPR)

Precedence Diagram Method (PDM) has hardly changed during the last few decades, despite the critiques voiced regarding its modeling capabilities. Traditional precedence relations are a subset of the point-to-point relations: in these cases, the end points of activities are connected, so they can be referred to as end-point relations [17]. Newly developed point-to-point relations are better from a theoretical and practical point of view than the solutions based on traditional precedence relationships, but they still cannot provide a theoretically perfect solution [17]. Professor Hajdu has offered a mathematical model and an algorithm for the point-to-point relations and problem model, and in doing so, has compared them with the traditional precedence relations [18, 19]. Figure 3 shows an example of a PTPPR.

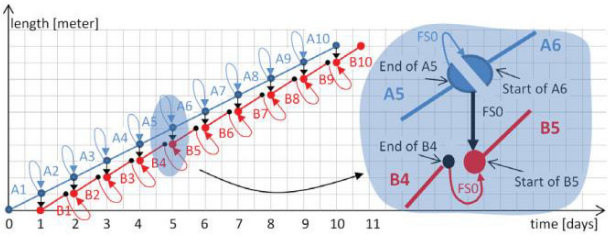


Fig. 3. Modeling Overlapped Activities Using Fragmentation and FS0 Relationships [17].

3. Methodology

3.1. Workshops

The mock-up project in this study is a three-story educational building in the city of Lima, Peru. In this case, the footprint area is 238 square meters per story. The construction processes are highly repetitive in each story. The structure works include: (1) vertical rebar; (2) vertical piping installation; (3) vertical electrical installation; (4)

vertical formwork; (5) vertical concrete pouring; (6) horizontal formwork; (7) horizontal rebar; (8) horizontal piping installation; (9) horizontal electrical installation; and (10) horizontal concrete pouring.

The purpose of the workshops is to present strategies for teaching the integration of *takt*-time, flowlines, and PTPPR methods. The workshops were led by one of the senior researchers and two additional research assistants. They were conducted with twenty-nine 4th-year students of Civil Engineering in the course entitled "CIV284: Construction Planning." This course primarily provides an understanding of planning and scheduling through lectures, workshops, simulations, and discussion periods. Topics covered in the course include project-integration management, project-scope management, project-time management, and project-cost management.

3.2. Workshop 1: Excel Spreadsheets and 2D Drawings

Traditional tools such as Excel spreadsheets and 2D drawings are used to teach production-system design with *takt*-time, flowlines, and PTPPR. Students are handed four different construction configurations (with different numbers of zones per story and different zone sizes). They then identify alternatives and analyze the four different construction options. For each alternative, they develop a *takt*-time, flowlines, and PTPPR schedules.

3.3. Workshop 2: 3D and 4D Models with Revit and Navisworks

A 3D model is created. Then 4D models are produced using Revit 2016 and Navisworks Manage 2016, integrating *takt*-time schedules (Workshop 1) with the 3D Model. Again, four different construction options are laid out. For each alternative, a *takt*-time schedule and 4D Model are generated. It is important to highlight that foundations, rebar, and mechanical, electrical, and plumbing (MEP) systems were not modeled, owing to didactical considerations.

3.4. Workshop 3: 4D and 5D models with Vico Office and Survey

Vico Office software is used for the automation of schedules and comparison of the *takt*-time and flowline methods. A questionnaire was designed to capture students' perceptions on the methods and the software used. The survey was conducted at the end of the workshop.

4. Results and Discussion

4.1. Workshop 1: Excel Spreadsheets and 2D Drawings

At first, students analyzed the *takt*-time, flowline, and PTPPR information presented on Excel spreadsheets and 2D drawings. Then they divided each story into zones or locations and designed the crews and materials needed to achieve a constant production flow. Nevertheless, students were not aware of the existence of clashes in the construction process because of the visual limitations inherent in 2D analysis. Students also had difficulties in creating flowlines—unlike with *takt-time* schedules, which are more easily created in Microsoft Excel. This is a barrier that also appears in real construction projects [20]. Finally, students paid more attention to visual management by the superposition of the PTPPR over the flowlines, simulating and comparing the planned work with the real work. An example of a comparison between the scheduled flowlines and PTPPR and those that were finally executed is shown in Figure 4.

4.2. Workshop 2: 3D and 4D Models with Revit and Navisworks

Here research assistants made a presentation on the 3D and 4D models that used the same information as the first stage. Students then visualized elements and the construction process. Even though the workshop helped them to gain new insights not allowed by traditional 2D drawings, the students also encountered some weaknesses of the 3D models. These include the following: (1) The 3D model is isolated. Whenever the *takt*-time schedule changes, all the related documents must be changed manually. (2) A 3D model for each construction alternative must be generated

(splitting elements according to each zone's borders); otherwise, quantity take-off for each alternative cannot be obtained properly. (3) It is not possible to integrate all project life-cycle information into a unique 3D virtual model.

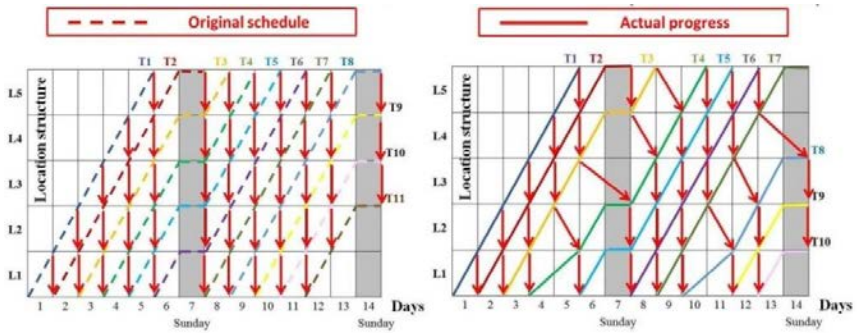


Fig. 4. Flowlines and Point-to-Point Precedence Relations [3].

Using Navisworks, students perceived the strengths of a 4D Model for planning and scheduling. They understood the potential of 4D models in the industry, where planners and project managers frequently must deal with weak understandings and few visual tools. Students were aware that the *takt*-time schedules were developed separately and then linked to the 3D model. At this stage, it is not possible to visualize Flowlines and PTPPR automatically from the 4D model in Navisworks. By the end of this workshop, students understood the strengths and weaknesses of 3D and 4D models compared to traditional 2D management. Figure 5 shows the 4D model of one alternative analyzed.

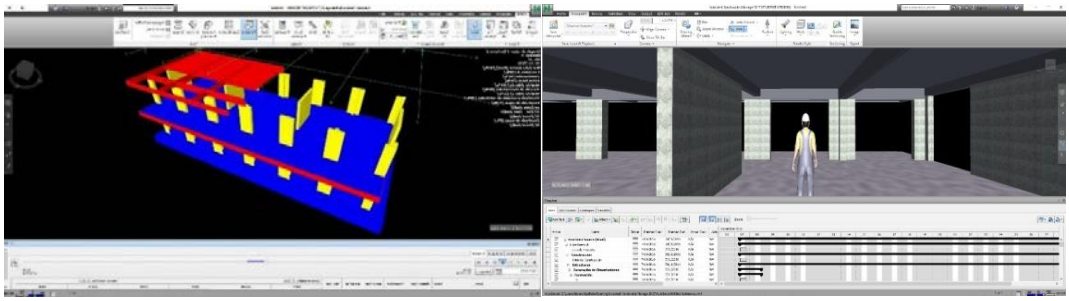


Fig. 5. 4D Model of One Alternative in Navisworks.

4.3. Workshop 3: 4D and 5D models with Vico Office

During the last workshop, students noticed that *takt*-time activities and flowlines could be related using a 5D model, in this case, by means the software program Vico Office. The main input to develop a 5D model is a previously made 3D model (Workshop 2). In this session, students realized how a 5D model integrates, in a unique virtual construct, all the planning and scheduling techniques and tools they had learned about during the course, and then easily links those elements with the cost. It was not an arduous task, due to the prior knowledge that allowed them to understand those processes, as evidenced in the results of the surveys. Once the model was completed and shown to the students, the research assistants introduced them to all the available information that could be automatically generated from this model, among them, the *takt*-time activities and flowlines. Figure 6 shows the presentation and the flowlines from Vico Office.

Likewise, students verified that each time that the 3D model or any element from the planning and cost section is modified, the 5D model is updated, and all the documents or outputs are immediately modified as well. To generate the 5D model, costs must be added, so we used some commercial values for the activities selected to show how the planning and cost management are closely related in this virtual model. We explained different ways of making

comparisons between initial costs and real or modified costs, and percentages of wastes, among others. The most valued benefits for the students were the following features: (1) The ability to access automated information, including the *takt*-time activities and flowlines; and (2) the relation between planning, scheduling, and cost management in a unique virtual model. The PTPPR is not automatically generated by Vico Office, but is simple to develop over the flowlines from the model. Figure 7 shows one example of *takt*-time activities and 5D costs.

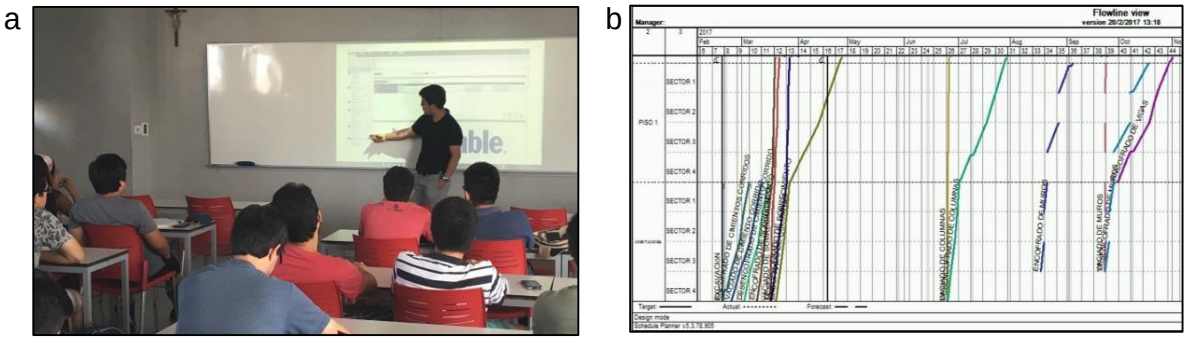


Fig. 6. (a) Explanation of Flowlines in Vico Office; (b) Generation of Flowlines.

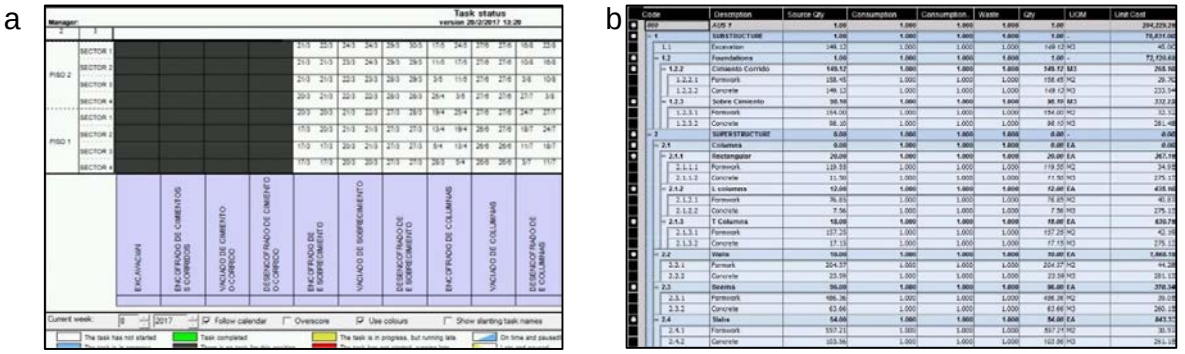


Fig. 7. (a) *Takt*-time in Vico Office; (b) Cost in the 5D Model Developed in Vico Office.

4.4. Survey

The survey was conducted at the end of the third workshop. Results are shown in Figure 8. Students scored each question on the Likert Scale from 1 to 5. A summary appears below.

- All students gave only the highest scores (4-Mostly Agree and 5-Definitely Agree) to the following questions: (i) The 4D model allowed for improved visualization of the construction process; (ii) The 4D model allowed for improved visualization of the construction zones (locations); (iii) The 4D model allowed for the discovery of construction-process clashes; (iv) I am interested in learning more about BIM; (v) In general, I believe that this workshop was useful in helping me get a better understanding of sectorization using 4D models as opposed to the 2D drawing; (vi) Using VICO Office software allows one to appreciate 4D (schedule, *takt*-time activities, and flowlines) and 5D models (+cost); (vii) PTPPR is useful for the visual management of the project; (viii) I would recommend that flowlines scheduling should include the PTPPR; (ix) I am interested in learning more about *takt*-time activities, flowlines, and PTPPR; (x) In general, I believe that this workshop was useful for helping me get a better understanding of sectorization using 4D and 5D models as opposed to the 2D drawings, Excel

spreadsheets, and traditional software. The extreme values were (ix) (Mean = 4.76, STD = 0.44) and (viii) (Mean = 4.17, STD = 0.38).

- The great majority agreed with the following: (i) Using the 4D model allowed for a greater appreciation of the differences in workloads between one location and another, in comparison to the 2D drawings; (ii) 4D model visualization in Vico Office (*takt*-time) allowed for the detection of construction-process clashes; (iii) 4D model visualization in Vico Office (flowlines) allowed for the detection of construction-process clashes. From the latter comments, we concluded that students have long been interested in BIM 4D and 5D.
- Finally, we asked two interrelated questions and obtained the following result: (i) Are *takt*-time activities better than flowlines? (Mean = 2.90, STD = 0.72); (ii) Are flowlines better than *takt*-time activities? (Mean = 3.1, STD = 0.72). These values show that students do not perceive much advantage for one method compared to the other.

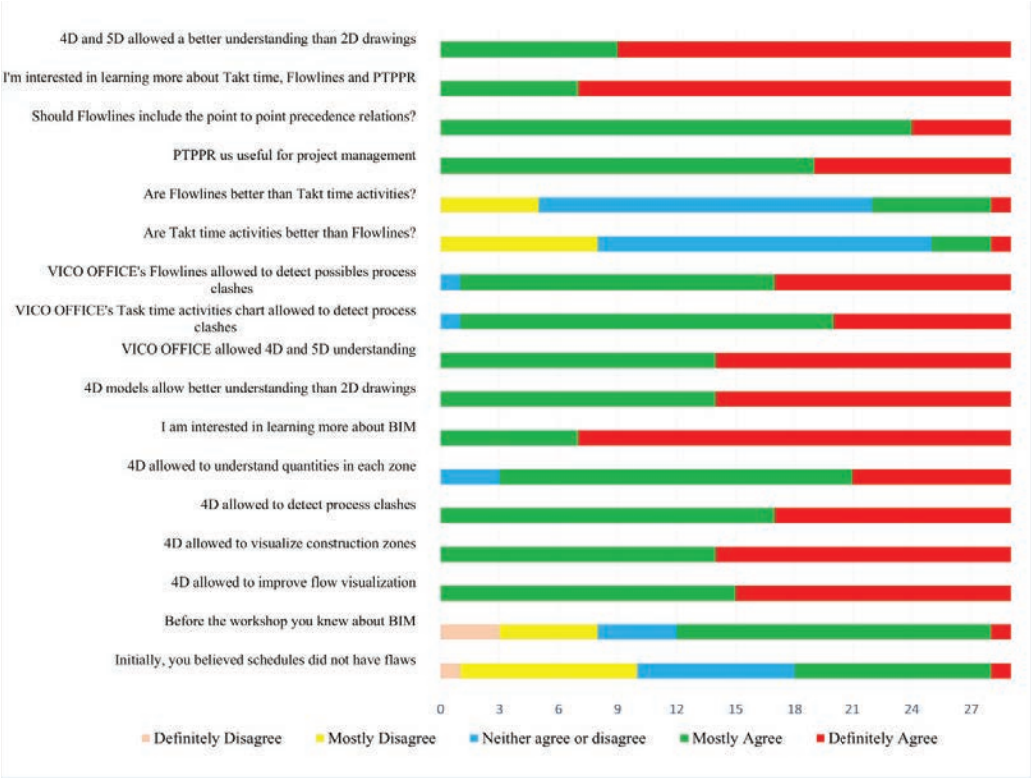


Fig. 8. Survey Responses Outline

5. Conclusions

This research into teaching strategies suggests that the use of BIM+ models, such as 4D and 5D, together with automated software, such as Vico Office, contributes to students' understanding of the concept and method of *takt*-time, flowlines, and PTPPR scheduling. Additionally, the use of advanced tools contributes to the selection of the best construction-flow alternative, labor allocation, and materials workflow. The survey helped to complement the qualitative data derived from the workshops. First, students' grasp of information integration using 3D, 4D, and 5D increased significantly. Second, a more holistic understanding of the project scope and construction process was achieved. Third, thanks to the use of a practical task with these BIM models in a case study, students were able to clarify any misunderstandings of the concepts from the course. Finally, the majority of the participants showed interest in learning more about the methods proposed in the workshops.

As consequence of these findings, researchers suggested to the Academic Coordinator of Undergraduate Studies in Civil Engineering at the Pontifical Catholic University of Peru that introduction to *takt*-time, flowlines and PTPPR be included in the course entitled "CIV284: Construction Planning." In-depth analysis, including simulation with software, was put forward as a necessary part of the courses "CIV321: Building Information Modeling" and "ING342: Lean Construction Management."

The survey results suggest that students do not find significant differences between *takt*-time and flowlines. They would be willing to use either one in construction planning, depending on the circumstances. This view is shared by many scholars in the field. It is also recommended to integrate flowlines and PTPPR to improve visual management of construction scheduling.

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