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VDC IN PRACTICE: INSIGHTS FROM PRODUCTION METRICS REPORTED AS USEFUL BY AEC PROFESSIONALS IN NORWAY

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ABSTRACT

Production metrics (PM) make it more likely for design and construction projects to stay on track through rapid feedback. 17 PM sub-categories from recent literature were used to label PM reported as useful by 155 AEC professionals enrolled in the 4th edition of a certificate program in Virtual Design and Construction in Norway (VDCCP). More than 36% of the professionals reported PM related to 2 sub-categories, i.e., plan adherence, and agenda items of collaborative sessions. Fewer than 5% of the professionals reported PM related to 6 sub-categories, i.e., inspections and punch lists, clash detection and resolution, rework during design, rework during construction, safety performance, and follow-up after collaborative sessions. This research extended a previous study by providing a more granular view of PM found useful by AEC professionals which had not been possible earlier. Comparing PM from the 4th edition of the VDCCP to those from the 1st edition indicated a maturity in the understanding of PM among enrolled professionals, emphasizing the importance of professional education in opening pathways for standardizing and benchmarking PM in the AEC industry.

KEYWORDS

Production metrics, continuous improvement, common vocabulary, benchmarking, VDC

INTRODUCTION

The rapid feedback provided by production metrics (PM) is in alignment with the core Lean Construction (LC) principle of continuous improvement (Haugstvedt, 2019) achieved through frameworks such as Plan-Do-Study-Act (PDSA) (Ballard and Tommelein, 2016; Fewings and Henjewele, 2019) and Define-Measure-Analyse-Improve-Control (DMAIC) (Banawi and Bilec, 2014; Hussain et al., 2019). However, the use of PM is still nascent in the Architecture, Engineering, and Construction (AEC) industry. PM are output metrics (Khanzode, 2011) which provide rapid feedback on how work is done by project teams on a daily-weekly basis. PM complement traditional cost and schedule variance-based metrics which focus on work progress (Majumdar, 2024). While a handful of PM, such as Percent Plan Complete (PPC), are gaining widespread adoption in the industry (Knotten and Svalestuen, 2014; Emdanat and Azambuja, 2016; Hamzeh et al., 2019), it has been difficult to assess whether there are other PM which AEC project teams could be tracking (Mischke et al., 2024). Despite research related to PM (Gao, 2011; Belsvik and Hjelseth, 2022), without consistent reporting from project teams based on a common vocabulary, it has been difficult to benchmark and standardize PM in the AEC

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industry (Majumdar et al., 2022). This is unlike manufacturing, where LC principles originated, and which now has industry-wide accepted PM (ISO 22400, 2014).

PM are an integral part of Virtual Design and Construction (VDC), a modern methodology for managing design and construction projects. Through a professional certificate program in VDC offered by Stanford University, the authors found an opportunity to develop a common vocabulary of PM consisting of 3 categories and 17 sub-categories, shown in Figure 1. While the authors have previously reported on the use of the 3 categories of PM (Majumdar et al., 2022), this study is the first which reports on the use of the 17 recently formalized PM sub-categories (Majumdar, 2024). The motivation for this study is based on the availability of new PM data through the latest edition of the certificate program in Norway. The newly acquired PM data also provided an opportunity for a longitudinal comparison of the 3 PM categories and 17 PM sub-categories between two cohorts of professionals enrolled in the program five years apart.

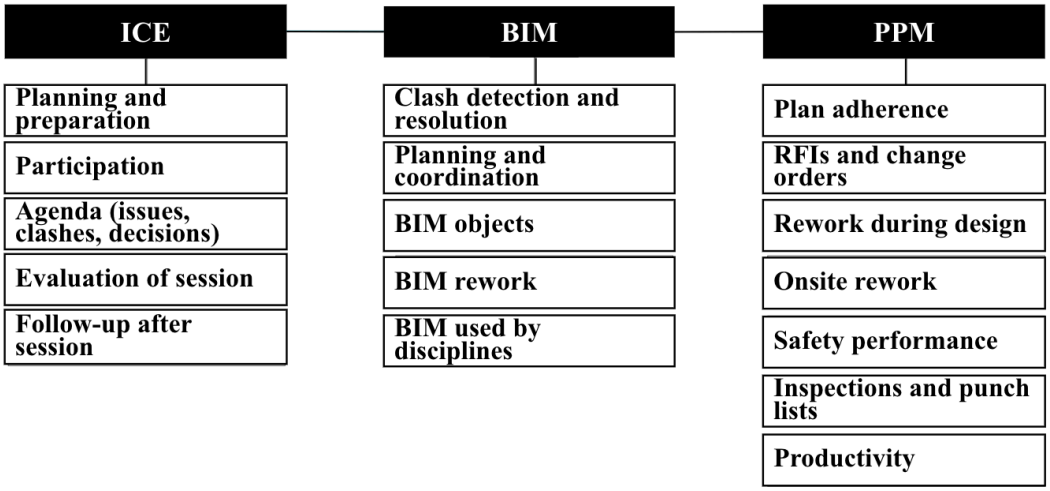

Figure 1: PM categories and sub-categories (Majumdar, 2024)

The rest of this section provides an overview of the certificate program. This is followed by a research methodology section, findings and discussion, limitations and future research directions, and conclusion.

THE VDC CERTIFICATE PROGRAM

In 2009, the Center for Integrated Facility Engineering (CIFE) at Stanford University, where the term VDC was coined, launched a professional certificate program to teach the VDC framework to AEC professionals in groups of 20-25 in different parts of the world. The VDC framework consists of the following three key elements:

- **ICE (Integrated Concurrent Engineering):** This pertains to collaboration among different disciplines to find good solutions to problems. The contribution of each discipline is maximized by working concurrently instead of sequentially (Fischer et. al, 2017).
- **BIM (Building Information Modeling):** This pertains to information about the building and the building process that can be used by other software for cost estimating, structural analysis, life-cycle assessment, etc. (Fischer, 2022). As BIM is not limited to visual information alone, it is used interchangeably with VIA (Visualization, Information integration, and Automation) in this paper.
- **PPM (Project Production Management):** This pertains to the workflows used in managing the production of design deliverables as well as assemblies on-site and in a factory setting. (Fischer et. al, 2017).

In 2019, the VDC certificate program began its 'large-scale' format by enrolling 203 AEC professionals from 46 companies in Norway through a partnership between the Stanford Center for Professional Development (SCPD) and the Norwegian University of Science and Technology (NTNU). While the certificate program has been running in other parts of the world as well, the scope of this paper is limited to the large-scale program in Norway, referred to as VDCCP throughout the paper. This is because of the association of the authors with the Norwegian program, as explained in the following paragraphs.

Components of the large-scale VDC certificate program in Norway (VDCCP)

- A 5-day introductory week conducted in-person consisting of lectures by Professor Martin Fischer from Stanford University, case studies presented by industry mentors with 5-15 years of experience who completed the program in previous years, and work-sessions for enrolled professionals.
- Monthly online check-ins of professionals with their mentors or group of mentors as they execute on their VDC implementation plans. The second author was a mentor in VDCCP1 and VDCCP2, and both the first and the second author were mentors in VDDCP3.
- 6 monthly reports submitted by professionals to show the progress of their VDC implementation, including the PM they used, and to receive written feedback from their respective mentors. Reports are submitted in .ppt format.
- A final summary report submitted by professionals explaining the results of their VDC implementation.
- A final 2-day workshop conducted in-person to assimilate learnings among professionals based on their VDC implementation journeys.

Since the launch of the 1st edition of the program in 2019, (VDCCP1), additional components have been introduced to the VDCCP based on feedback from enrolled professionals and mentors. These include a 2-day mid-term workshop focused on PM, an increase in the number of mentors for each group of enrolled professionals, and involvement of senior mentors, i.e., industry experts who have acted as mentors in one or more previous editions of the program. The term BIM was replaced by VIA in the ongoing 4th edition of the program, i.e., VDCCP4. Since its launch, 756 AEC professionals have completed different editions of the VDCCP, as shown in Figure 2.

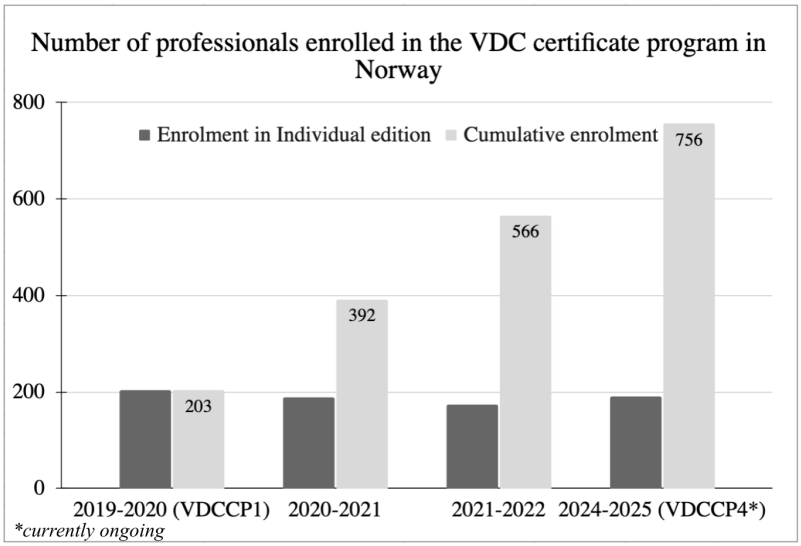

Figure 2: Number of AEC professionals enrolled in different editions of the VDCCP (VDCCP4 is currently underway).

The second author is currently a senior mentor in VDCCP4 and was able to gain access to the latest PM data collected through its mid-term workshop. This was the first time that new PM data from the VDCCP was available after the 17 sub-categories were formalized, which motivated this study. As such, this study reports on findings from PM data of VDCCP4 to answer the following research question:

What insights can be gained from a) 17 PM sub-categories reported as useful by professionals enrolled in VDCCP4, and b) a longitudinal comparison of 3 PM categories reported as useful across VDCCP1 and VDCCP4?

RESEARCH METHODOLOGY

The research methodology for this study built on the previous study based on PM collected from VDCCP1. Key research tasks included: 1) acquiring PM data from professionals enrolled in VDCCP4, 2) cleaning up PM data to conduct the 1st round of categorization using the 3 PM categories, i.e., ICE, BIM, and PPM, 3) conducting the 2nd round of categorization using the 17 PM sub-categories, and 4) comparing PM across VDCCP1 and VDCCP4. The authors have previously carried out tasks 1, 2, and 4 on PM data available from different editions of the VDCCP prior to VDCCP4. Task 3 was not possible earlier because the 17 sub-categories were not available then. As highlighted in Figure 3, the research methods used in this study were the survey method for task 1, and qualitative double coding for tasks 2 and 3. Once the PM data was labelled into categories and sub-categories, the authors collaboratively compared the PM data from VDCCP4 to that from VDCCP1 based on a) evidence of the 3 categories of PM reported as useful, and b) the percentage of discarded PM.

Unlike the previous study, in which content analysis (Elo and Kyngas, 2008) was used as the research method to extract and label PM found in the final monthly reports submitted by professionals, the survey method was considered reasonable for collecting PM data from the mid-term workshop of VDCCP4. Prior work related to this study was inductive in nature because it was important to understand which categories and sub-categories were emerging from the PM reported as useful by professionals through their final monthly reports. With a formalized classification of categories and sub-categories already in place by the time the VDCCP4 was launched, a deductive approach to labelling the PM was possible through a 'free-text' based survey. The method of double coding (He, 2021) was considered suitable for this. Double coding is used for qualitatively coding data such as that obtained from open-ended questions in surveys. Two or more researchers independently analyze the data, assign, and reconcile the labels collaboratively or with the help of an expert. As both the authors have acted as experts in multiple editions of the VDCCP, involving a third expert was not considered necessary for this study.

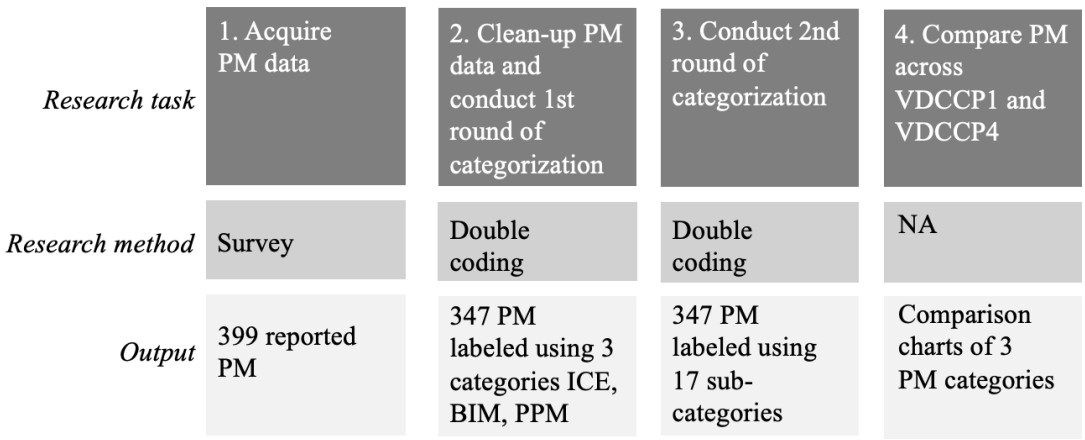

Figure 3: Research methodology

1. Acquiring PM data from professionals enrolled in VDCCP4:

PM reported as useful by 191 professionals enrolled in VDCCP4 were acquired through a survey administered during the mid-term workshop. The survey, consisting of four questions, was administered to professionals as a Nettskjema form, an online, browser-based service developed by the University of Oslo to create, save, and manage surveys and data collection. Nettskjema provides a higher level of security for access and data as compared to other services, and is therefore preferred by universities and public institutions in Norway. The Nettskjema form used for this study was administered through NTNU.

Of the four questions in the survey, the one relevant for this paper is: *Which 2-5 PM have been most useful to you so far?* The PM sub-categories were not shared with the professionals to encourage them to truly think through PM which mattered the most to them and to avoid bias in reporting. As such, professionals were expected to enter their responses as 'free text'. The timing for administering the survey was considered suitable as the professionals had participated in the introductory week and had gone through three months of mentorship on their VDC implementations, which included feedback on the PM they had defined for the scope of work they were managing. Survey responses were saved as a .xls file and immediately anonymised.

2. Cleaning up PM data to conduct the first round of categorization using 3 PM categories:

The authors interpreted and categorized each of the 399 PM reported through the survey. Each PM was either categorized as ICE, BIM, PPM, or was discarded if it was a) a vague statement, such as "visualization of model", b) an input metric which the professional could control, such as "sending meeting invitations to participants 1 week in advance", or c) a one-time measurement done at the end of the project or at specific project milestones, such as "commissioning approved". In this way, the cleaned-up PM data consisted of 347 PM which were daily/weekly output metrics and represented 155 professionals.

3. Conducting the 2nd round of categorization using 17 PM sub-categories:

The authors carried out a second round of categorization of the 347 PM using the 17 categories from Figure 1. While the process of interpreting and categorizing each PM was similar to the first round, assigning the sub-categories demanded a more detailed understanding of the context in which the PM were tracked by the professionals. As the second author is a senior mentor in the currently ongoing VDCCP4, she was able to interpret each PM and the context in which it was reported. The authors assigned the sub-categories to each PM based on mutual consensus to align independently coded data.

4. Comparing PM to those from VDCCP1:

The first round of categorization was based on the 3 categories established in the previous study, i.e., ICE, BIM, and PPM. Categorization of PM from VDCCP1 had revealed that 84% of 115 professionals found PM related to ICE as most useful, followed by 68% for PPM and 30% for BIM. Additionally PM reported by 35% of the professionals from VDCCP1 had to be discarded. These categorizations and the discarded PM were compared to those from VDCCP4. Results of the comparison are stated under the findings section of this paper.

FINDINGS

This section provides results of the categorization and comparison of PM across VDCCP1 and VDCCP4. The result of the 2nd round of categorization of PM from VDCCP4 is presented first as this was the first time the 17 categories were used for labelling PM found useful by professionals.

Findings from the 2nd round of categorization using 17 PM sub-categories:

The cleaned-up PM data from VDCCP4 represented 155 professionals working on different types of projects (building: 55%, infrastructure: 42%, not known: 3%) representing different types of companies (owner: 19%, designer / consultant: 28%, contractor: 48%, other: 6%). 2 sub-categories were reported as useful by more than 36% of the 155 professionals while 7 sub-categories were reported as useful by fewer than 5%, as shown in Figure 3. PM related to plan adherence and ICE session agenda were reported by 36% and 40% of the professionals respectively. PM related to inspections and punch lists, clash detection and resolution, rework during design, BIM/VIA rework, onsite rework, safety performance, and follow-up after ICE sessions were reported by fewer than 5% of the professionals. Evaluation of ICE sessions, and productivity were reported by 16% and 21% of the professionals respectively. PM reported as useful by 9-12% of the professionals were related to ICE session participation, use of BIM/VIA by disciplines, BIM/VIA planning and coordination, BIM/ objects, ICE planning and preparation, and RFIs and change orders.

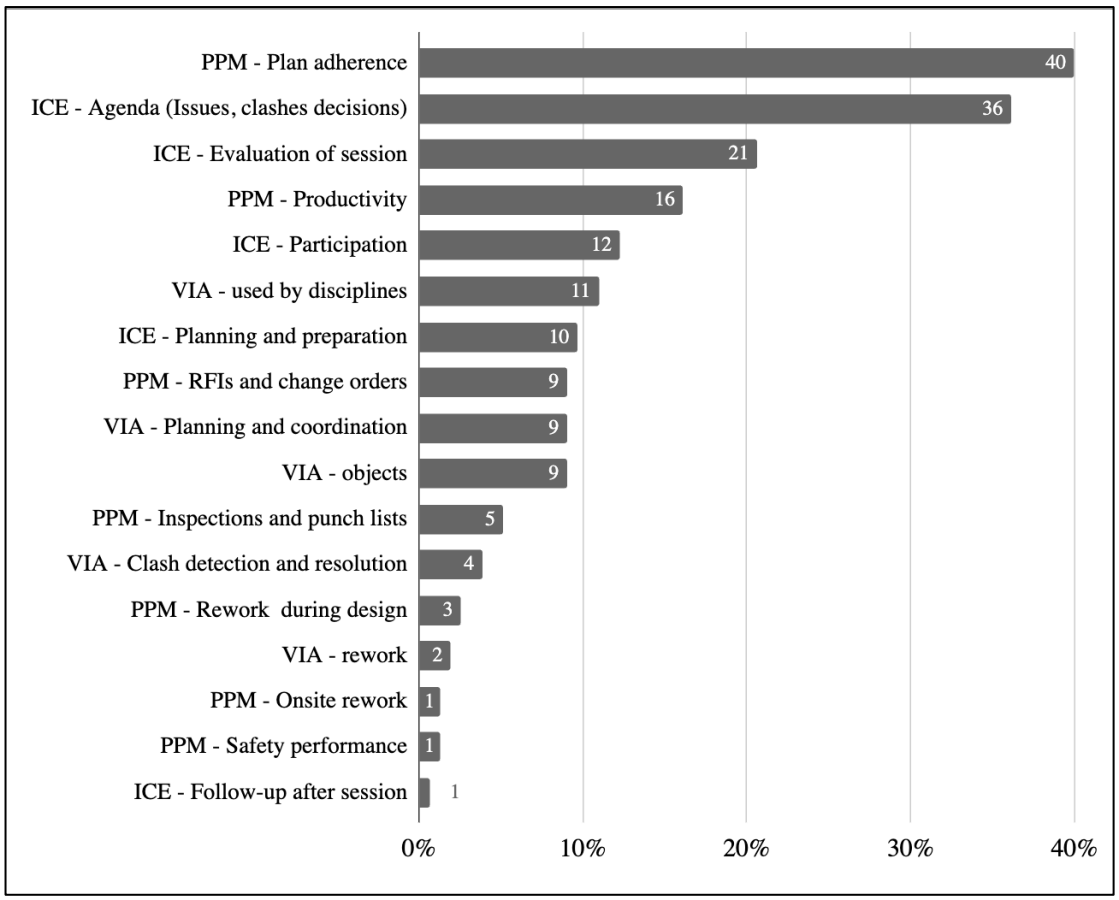

Figure 4: Percentage of professionals from VDCCP4 who reported production metrics representing each of the 17 sub-categories.

Findings from the comparison of PM categories across VDCCP1 and VDCCP4:

Most professionals in VDCCP4 represented contractors (48%), while most professionals in VDCCP1 represented designers/consultants (41%), as shown in Table 1. 19% of the professionals enrolled in VDCCP4 did not report any PM which could be included in this study, based on the inclusion criteria for PM explained in the research methodology section. In comparison, 34% of the professionals enrolled in VDCCP1 had not reported any PM in their final monthly report which could be included in the previous study. 13% of the PM from VDCCP4 had to be discarded as compared to 66% of the PM from VDCCP1.

Table 1: Company types and project types represented by professionals enrolled in VDCCP4 (Data from VDCCP1 provided for comparison).

		VDCCP4 (n=155)	VDCCP1 (n=115)
Company Type	Owner	19%	19%
	Designer/Consultant	28%	41%
	Contractor	48%	35%
	Other	6%	5%
Project Type	Building	55%	44%
	Infrastructure	42%	52%
	Not known	3%	4%

PM categorized as BIM were reported by 30% of the professionals in both VDCCP1 and VDCCP4. PM categorized as PPM were reported by 63% of the professionals in VDCCP4 as compared to 68% in VDCCP1. PM categorized as ICE had disparity in reporting (VDCCP4: 55%, VDCCP1: 84%). Figure 5a. shows this comparison.

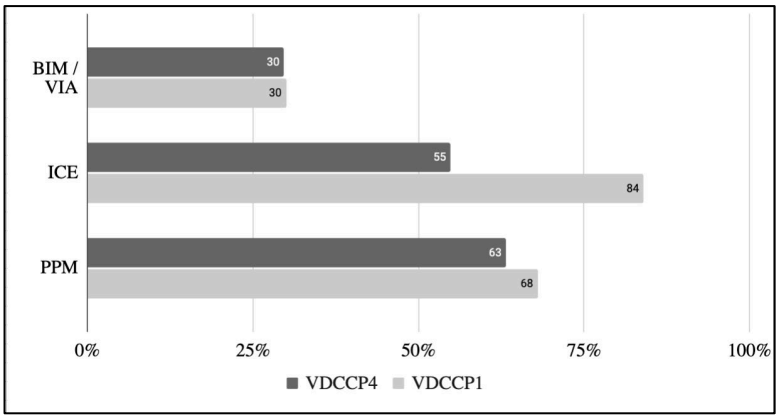

Figure 5a: Percentage of professionals who reported production metrics representing ICE, BIM or VIA, and PPM in VDCCP4 (n=155) and VDCCP1 (n = 115).

VDC researchers have recommended using all the three VDC elements for maximum benefit to the project (Rischmoller et al., 2018). Most professionals in VDCCP4 reported PM representing PPM only (31%). In comparison, most professionals in VDCCP1 had reported PM representing 2 categories, i.e., ICE and PPM (39%), as shown in Figure 5b.

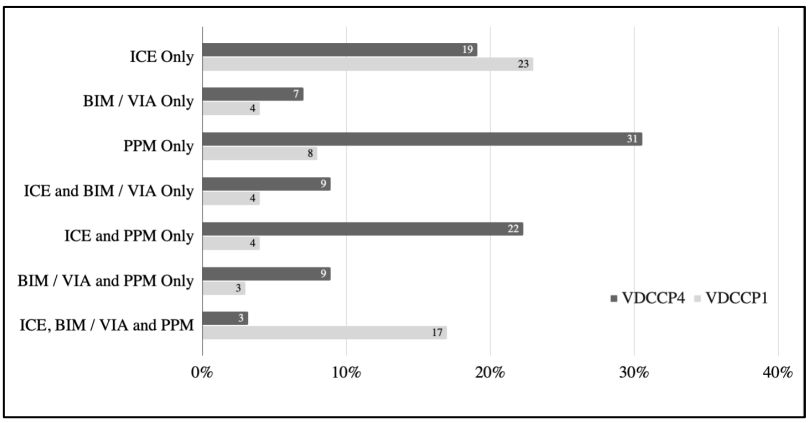

Figure 5b: Percentage of professionals who reported production metrics representing 1, 2, or 3 PM categories in VDCCP4 (n=155) and VDCCP1 (n = 115).

DISCUSSION ON FINDINGS

On the 17 PM sub-categories:

The survey specifically asked for 2-5 most useful PM, which might explain why 7 PM subcategories were reported by fewer than 5% of the professionals as they likely reported those which they found to be most useful for the scope of work they were directly managing. As an example, while project managers would have found PM related to clash resolution useful, they likely reported PM related to decision making and plan adherence as most useful. Additionally, professionals may not have reported certain PM which are mandatory in the Norwegian construction industry, such as those related to safety.

PM data from VDCCP1 had indicated that most professionals reported PM related to ICE session evaluations and participation. At that time, the program had just taken off and professionals were likely over-reporting PM which were easy to measure. Results from this study with PM related to ICE agenda, issues, clashes, and decisions being reported as most useful suggest a more mature understanding of PM among professionals. Under plan adherence, PPC continued to be reported as the most useful, indicating its potential to become the first industry-wide standard PM in Norway.

On the comparison of PM across VDCCP1 and VDCCP4:

Collaboration is one of the fundamental principles of LC, which has been popular in Norway for some time now. Companies in Norway are known for their flat organizational structure, and leadership which involves employees in decision-making. Therefore, it is not a surprise that PM categorized as ICE were reported by more than 55% of the professionals in both editions of the program.

PM under the PPM category, reported by more than 63% of the professionals in both the editions, are closely related to plan adherence, including the Last Planner, which has gained popularity in Norway in recent times. PPC, with its roots in LC, emerged as the PM which was most reported in both the editions.

PM categorized as BIM/VIA were reported by 30% of the professionals in both VDCCP4 as well as VDCCP1. Typical AEC companies in Norway have a small group within every project which manages technical aspects of BIM. Others use BIM as a tool to access information relevant to their specific process or task. As such, it is unlikely for professionals in roles other than BIM Manager or BIM coordinator to track and report PM related to BIM objects, their classifications, and databases which the BIM might be connected to. While it is common practice in Norway to use BIM in ICE sessions, reporting from such sessions focuses on PM such as the number of tasks completed or decision made, which are not categorized as BIM.

The percentage of discarded PM (13%) in this study will likely reduce by the time VDCCP4 is complete as PM data for this study was collected during the mid-term workshop and the enrolled professionals have several more months of learning ahead of them. The dramatic decrease in discarded PM as compared to VDCCP1, in which 66% of the PM had to be exluded from the previous study, and the reduced percentage of professionals who represented them indicates an improvement in PM learning among professionals enrolled in the VDCCP over the years. The time taken to process the PM data collected also reduced dramatically from VDCCP1 to VDCCP4. The entire cycle of collecting, interpreting, labeling, and validating PM data from VDCCP1 had taken over a year. Because professionals did not have a commonly understood PM vocabulary then, the authors had to follow an inductive approach of qualitative coding to label each of the 1392 PM and to validate the labelling with the mentors. In comparison, it took the authors one week to label the 399 PM by following a deductive approach of qualitative coding using the recently published PM classification.

LIMITATIONS AND FUTURE WORK

This study utilized new data available through the mid-term workshop in the ongoing VDCCP4 to report on 17 recently established PM sub-categories. While it provided an understanding of PM sub-categories found useful in practice, connecting the PM to a) project outcomes and b) practices which may influence the performance of these PM was beyond the scope of this study and should be considered by future researchers. This study relied on PM reported mid-way during VDCCP4. It is likely that enrolled professionals will add or delete some PM in the future based on their project context and increased understanding of PM by the time VDCCP4 ends. Therefore, future research should explore how the use of PM changes over the lifecycle of a project and over the course of educational programs, such as the VDCCP. Findings from this study indicate that the Norwegian construction industry is gaining a common understanding of PM through the VDCCP. However, future research should explore whether and which PM from the program are adopted or standardized in the companies represented by the professionals.

CONCLUSIONS

PM operationalize the conceptual underpinnings of continuous learning in Lean Construction research. They provide rapid feedback on actions and decisions taken by project teams during run-time, making it more likely for projects to stay on track. Without standardized lists of PM expressed in a commonly understood vocabulary, AEC professionals struggle to establish PM on their projects. This leads to inconsistent reporting of PM, hindering comparison and benchmarking.

Using a PM classification consisting of 17 sub-categories published recently, this study categorized PM reported as useful by 191 AEC professionals enrolled in the ongoing edition of a certificate program in Norway. More than 36% of the professionals reported PM related to 2 of 17 subcategories, i.e., plan adherence and ICE session agenda items. Fewer than 5% of the professionals reported PM related to 6 of 17 subcategories, i.e., inspections and punch lists, clash detection and resolution, rework during design or construction, safety performance, and follow-up after collaborative sessions.

This study also compared PM across two editions of the program using previously published PM categories, i.e., ICE, BIM, and PPM. PM related to PPM were reported as useful by more than 65% while those related to BIM/VIA were reported by fewer than 30% of the professionals in both the editions of the program. There was a disparity in PM related to ICE. 13% of the PM from the ongoing edition had to be discarded from the study as compared to 66% of the PM from the first edition of the program, indicating an improvement in the understanding of PM among enrolled professionals.

This research extended a previous study of PM reported as useful across different groups of professionals, operationalized a recently published PM classification, and provided evidence of maturity in understanding of PM among AEC professionals enrolled in an educational program. It opened pathways to repeating useful PM on AEC projects, benchmarking PM in AEC companies, and standardizing PM in the AEC industry.

ACKNOWLEDGMENTS

We thank all the professionals and mentors who have participated in different editions of the large-scale VDC certificate program, especially those in VDCCP1 and VDCCP4. We thank Steinar Rasmussen for coordinating VDCCP4. We thank Prof. Martin Fischer and Prof. Eilif Hjelseth for providing research guidance and for their leadership in running the program. The program is moving the needle in the construction industry in Norway towards the adoption of Lean and VDC practices. We are grateful for being a part of the community of VDC mentors globally.

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