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VDC IN PRACTICE: A PRELIMINARY CATEGORIZATION OF PRODUCTION METRICS REPORTED IN SCANDINAVIA AND LATIN AMERICA

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ABSTRACT

Architecture, Engineering and Construction (AEC) teams are increasingly using emerging management methods involving collaboration, lean construction, and digitization for managing projects. Production metrics (PM) are being used to assess the impact of these methods on project performance during run-time. A lack of common vocabulary hinders comparison of PM, making it difficult to repeat strategies used for improving project performance and for benchmarking PM across projects.

Through a detailed content analysis, 2 datasets of 904 PM reported by 195 Virtual Design and Construction (VDC) practitioners in Scandinavia and Latin America were curated. Qualitative coding was used to categorize the PM into the three key VDC elements, i.e., Integrated Concurrent Engineering (ICE), Building Information Modeling (BIM) and Project Production Management (PPM) and to validate the categorization.

This research enabled a comparison of PM categories across the two regions for the first time. PM categorized as ICE and PPM were reported by more than 68% professionals in both the regions. BIM PM had a disparity in reporting (Scandinavia: 30%, Latin America: 91%). It also opened a pathway to develop a common vocabulary of PM to compare, benchmark and standardize PM across VDC implementations.

KEYWORDS

Production metrics, continuous improvement, concurrent, standardization, process

BACKGROUND

Since 2019, the Stanford Center for Professional Development (SCPD) has been conducting a VDC certificate program (VDCCP) in collaboration with the Center for Integrated Facility Engineering (CIFE), Norwegian University of Science and

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Technology (NTNU) and Universidad De Lima (ULima). AEC professionals enrolled in the VDCCP learn the fundamentals of VDC in a 1-week introductory workshop and implement VDC on their ongoing projects for 9 months. They define PM for their projects at the beginning of the implementation and explain through monthly reports if and how the PM enabled effective course correction.

INTRODUCTION

Previous researchers have established the connection between Lean and VDC (Fosse & Ballard, 2016; Rischmoller et al., 2018). In recent years, there has been an increase in the number of AEC professionals implementing VDC on their projects (Majumdar et al., 2022). PM are an integral part of the VDC methodology. They impact project performance by providing rapid feedback on actions and decisions taken by project teams for timely course correction. Unlike several other industries, such as manufacturing, a common vocabulary of useful PM does not exist for the AEC industry. As a result, AEC project teams establish and track PM on an ad-hoc basis, which hinders comparison and benchmarking. This phenomenon was observed by CIFE researchers in the PM data provided by 279 AEC professionals from Scandinavia and Latin America who enrolled in the VDCCP in 2020.

This was the first time that PM data from a large number of projects in two different parts of the world during the same time period was available for research. This opened up the possibility of building a vocabulary of PM to facilitate learning and benchmarking and to answer the research question - *How can PM data be used for comparison and learning across projects?*

In answering the above question, this study categorized 1963 PM using the 3 key VDC elements of ICE, BIM, and PPM. While an analysis of individual PM in each of the 3 categories is beyond the scope of this study, it makes the following two contributions:

- A categorization based on key VDC elements as a first step towards building a common vocabulary of PM.
- Operationalization of VDC theory by comparing PM categories reported in practice.

Project Managers and AEC organizations can use this categorization to compare the level of collaboration, use of digital tools and lean work processes across projects. They can establish and standardize individual PM under each category. Researchers can use this categorization to build sub-categories of PM to facilitate standardization of PM in the industry.

POINT OF DEPARTURE

PM, an integral part of the VDC methodology, create a culture of continuous improvement, which is a key Lean principle (Haugstvedt, 2019).

Existing literature on PM used by VDC practitioners is either based on anecdotal information (Kunz & Fischer, 2012) or limited case studies (Belsvik et al., 2019; Fosse & Ballard, 2016; Gao, 2011). There has been no study which reports on PM used in practice on a variety of projects. This empirical research looked for evidence of PM used by VDC practitioners on ongoing projects in two different parts of the world in 2020 and categorized them for accessibility by AEC professionals and researchers.

Categorization of metrics has been adopted in other industries, such as manufacturing, for comparison, benchmarking and standardization (Gunasekaran et al., 2001). In the AEC industry, categorization has been used for comparison of facilities performance (Lavy et al., 2014). This is the first study which uses PM data reported from real AEC projects and uses the following key VDC elements to categorize them:

ICE (Integrated Concurrent Engineering): To achieve an integrated, high performing facility, project teams should learn how to share knowledge, evaluate multiple possible solutions through collaboration and consistent feedback. It therefore becomes important for the project team to co-locate, at least partially (Fischer et al., 2014) so that project team members from various disciplines can have several quality interactions to solve problems quickly and effectively.

BIM (Building Information Modeling): This refers to visualization and simulation, which are the key mechanisms to achieve integrated information.

PPM (Project Production Management): This refers to the organization of physical work tasks by treating the project as a production system. It includes managing parameters such as cycle time, work in process, capacity utilization etc. PPM has its origins in Operations Science, which is also the seat of evolution of Lean (Rischmoller et al., 2018).

RESEARCH METHOD

Conceptual content analysis was considered suitable for this study. This research method establishes whether a concept exists in a given text. The occurrence or non-occurrence of selected keywords within the target text are used to either discern the central idea of the text or extrapolate conclusions (Carley, 1990). This was used to extract PM data from each final report in .ppt or .pdf format provided by AEC professionals as part of the VDCCP and then to categorize them. Without a standard list of PM available, the survey method would be inadequate to capture the data provided in all the reports and was, therefore, ruled out. Case studies or sampling would not cover the breadth of PM data which was available for the first time, and were also ruled out.

RESEARCH TASKS

The key tasks in the research involved a) data preparation and clean-up to curate two datasets of PM, b) qualitative coding to categorize PM reported in dataset 1(Scandinavia) into the three key VDC elements, i.e., ICE, BIM and PPM, and c) qualitative coding of PM reported in dataset 2(Latin America) to validate the three PM categories.

DATA PREPARATION AND CLEAN-UP

Final monthly reports (in .ppt or .pdf formats) submitted by 175 professionals from the first large-scale VDCCP in Scandinavia and by 104 professionals from the first large-scale VDCCP in Latin America were compiled. The data was immediately anonymized for carrying out the research. The languages used in the reports were Norwegian, English and Spanish. 1963 PM found in these reports in the form of tables and charts were manually entered in Google sheets in the original language and were translated into English using Google Translate. As PM are daily or weekly in nature and are measured as short-term outcomes of actions and decisions taken by the project team, data clean-up was done to eliminate metrics which are a) measured once at project completion instead of daily or weekly, such as “deviation from final cost of project”, b) measured at specific milestones, such as “time taken to complete zoning plan”, c) input metrics (Khanzode, 2011) which are actions and decisions controlled by the project team and do not measure an outcome, such as “number of ICE sessions conducted, and vague data reported as metrics, such as “problem solving”.

After clean-up, dataset 1 consisted of 417 PM reported by 115 professionals and dataset 2 consisted of 487 PM reported by 80 professionals. Tables1 and 2 provide details on the roles of professionals in both the datasets after clean-up and the project types they reported PM data from.

Table 1: Role of professionals in cleaned-up datasets of PM

Company Type	Dataset 1 Scandinavia (n=115)	Dataset 2 Latin America (n=80)
Owner	8%	24%
Consultant/Owner's Rep.	11%	2%
Design/Engineering Consultant	41%	11%
General Contractor	33%	41%
Subcontractor	2%	15%
Software Provider	5%	4%
Not Available	0%	4%

The professionals used VDC on both building and infrastructure projects. Table 2 lists the breakdown by these 2 project types after data clean-up in the two datasets.

Table 2: Project types in cleaned-up datasets of PM

Project Type	Dataset 1 Scandinavia (n=115)	Dataset 2 Latin America (n=80)
Building	44.3%	83.8%
Infrastructure	52.2%	10.0%
Information not available	3.4%	6.3%

CATEGORIZATION OF PM IN DATASET 1

Through content analysis, the first author interpreted the 417 cleaned-up PM from dataset 1 using supporting documentation from the monthly reports before categorizing it. The interpretation was reviewed by industry experts from Scandinavia who had participated as mentors to the professionals during the VDCCP and were therefore familiar with the context of the projects in the reports. The second and fourth authors then did another review of the PM interpretation and categorization and updated the categories where required. For PM which were categorized differently by different authors, a mutual decision was taken to select one category over another. A few PM were found which satisfied the criteria of more than one category. As an example, “number of clashes identified in the 3D BIM during the ICE session" can be categorized as both BIM and ICE. For such PM too, a mutual decision was taken by the authors to select one category over another.

VALIDATION OF PM CATEGORIZATION IN DATASET 2

The process to interpret and categorize PM was repeated for dataset 2. After the first author interpreted the 487 cleaned-up PM, a second round of interpretation was carried out by the third author, a researcher from the University of Lima who was also the program coordinator for the VDCCP. Once a PM was interpreted adequately, a mutual decision was taken to categorize it. No PM was found in dataset 2 which could not be categorized into the 3 key VDC elements of ICE, BIM, and PPM, validating the proposed categorization.

FINDINGS AND DISCUSSION

The categorization of PM enabled a comparison of PM across the two datasets. Manual data analysis of the categorized PM highlighted a) the most reported PM category and b) the number of PM categories reported by AEC professionals across the two datasets

COMPARISON OF PM CATEGORY

As shown in Figure 2a, PM which were categorized as ICE were reported by more than 80% professionals in both the datasets (Scandinavia: 84%, Latin America: 91%). PM categorized as PPM were reported by more than 65% in both the datasets (Scandinavia: 68%, Latin America: 79%). There was a disparity in the number of professionals who reported PM which were categorized as BIM (Scandinavia: 30%, Latin America: 91%).

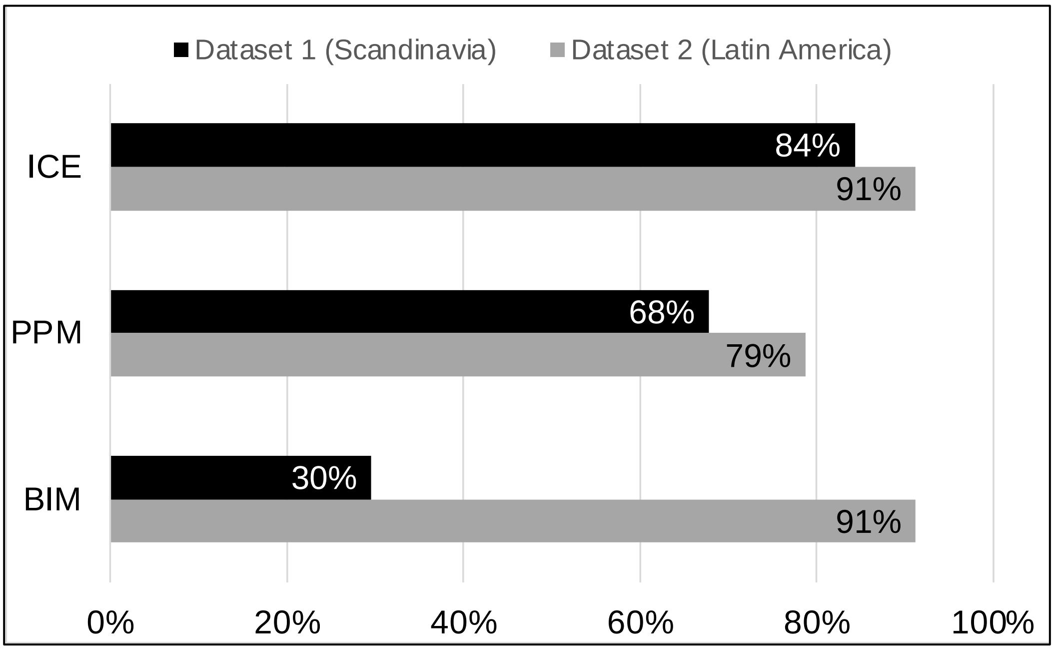

Figure 2a: Percentage of professionals who reported ICE, BIM, and PPM production metrics in Scandinavia (Dataset 1, n =115) and Latin America (Dataset 2, n = 80)

- ICE: ICE emerged as the PM category reported by most professionals in both the datasets, indicating that collocation and collaboration are picking up as a way of working across the geographies. This finding can be used by project managers and AEC organizations to invest in resources which foster collaboration, such as the big room (A. Khanzode et al., 2011.). Organizations can define standard lists of individual ICE PM which can assist project teams to assess team collaboration. Software providers can focus on product functionality which enables assessment of collaboration and recommends strategies to improve it.

- PPM: A large number of professionals across both the datasets reported PM in this category. PM which were categorized as PPM bear a resemblance to metrics tracked on traditional projects, such as "number of change orders" and "number of requests for information", indicating that they may be better understood by professionals as compared to BIM PM. "Percent Plan Complete" was the PM which was most reported in this category across both the datasets.
- BIM: It was surprising to see BIM PM being reported by only 30% of the professionals in dataset 1 as compared to 91% professionals in dataset 2. The PM which most professionals reported under BIM was the "number of clashes detected or resolved". Hard clashes, which may be better understood in the industry, are more common in building projects (Matejka & Sabart, 2018). 44% of the professionals in dataset 1 were working on building projects as compared to 84% in dataset 2. When standardizing and benchmarking PM, organizations should consider the project type.

NUMBER OF PM CATEGORIES REPORTED

Figure 2b shows the count of professionals who reported PM representing all three VDC elements (Scandinavia: 17%, Latin America: 68%) as compared to those who reported PM representing a single VDC element (Scandinavia: 36%, Latin America: 6%)

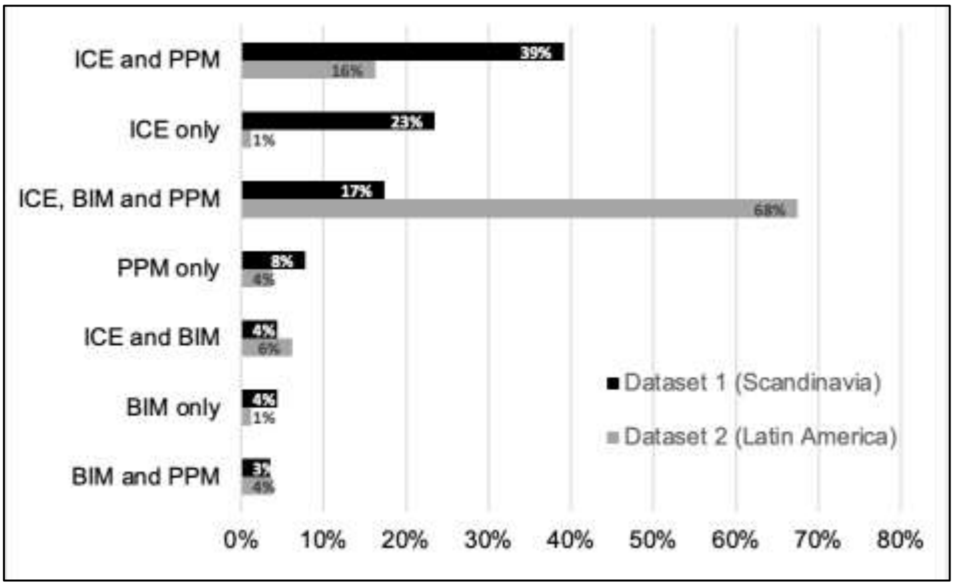

Figure 2a: Percentage of professionals who reported production metrics representing 1, 2 and 3 VDC elements, i.e., ICE, BIM, and PPM in Scandinavia (Dataset 1, n =115) and Latin America (Dataset 2, n = 80)

There was a disparity in the number of professionals who reported all the three categories of PM across the two datasets. Most professionals in dataset 2 reported PM in all the three categories while most professionals in dataset 1 reported PM in two categories. A handful of professionals reported PM in a single category. Almost 40% of the professionals in dataset 1 and 16% professionals in dataset 2 reported PM which could be categorized as ICE and PPM but none which could be categorized as BIM.

LIMITATIONS

The categorization recommended in this paper is based on self-reported PM data from the VDCCP. Monthly reports provided evidence of the use of PM in the form of pictures, tables, charts, and summaries. Triangulation, in the form of reviewing actual artefacts from the projects (such as projects schedules, RFI and change order logs), was beyond the scope of this work. While it is possible that certain PM used were not reported due to confidentiality, such PM would likely fall under one of the three categories recommended in this paper.

While this study provided insight into 3 broad categories of PM reflecting project organization, tools for visualization and simulation and processes for work tasks, it did not provide a comprehensive list of individual PM reported under each category. Comparing projects based on PM category alone is not sufficient. Individual PM for each category need to be compared for establishing benchmarks across projects.

This study did not consider differences in PM reported based on project type and phase For example, BIM PM related to hard clashes may not have been relevant for infrastructure projects. Similarly, PM related to field material delivery and site generated change orders were not relevant for projects in the design phase. Project managers should consider these factors while comparing projects based on the PM categories reported.

It is possible that a certain PM category was reported more than another because of familiarity or ease of tracking. As an example, “number of change orders”, which have traditionally been managed on construction projects and are categorized as PPM, are possibly better understood by professionals. In comparison, PM related to BIM and ICE may not be understood very well. Companies should therefore put in effort towards training employees to familiarize them with BIM and ICE PM. Developers of BIM tools should expand functionality of solutions so that it is easy for professionals to track BIM PM such as “BIM rework hours”.

A few PM, such as “number of tasks in the weekly lookahead plan”, if identified in an ICE session, could have been categorized in more than one category. This study did not consider PM categories by combinations of VDC elements. However, the number of such PM found in this study was not significant to alter the results of the comparison.

FUTURE RESEARCH

This study provides a categorization of PM into the three key elements of VDC. Future research should:

- Include more PM data from projects in other geographies to further validate sufficiency of the three categories. In addition, PM reported by AEC professionals who did not go through the VDCCP should be included to test the applicability of the categorization.

- Define individual PM under each of the three categories. Project managers and companies will then be able to identify the top individual PMs tracked under each category to establish benchmarks.
- Compare PM categories based on project characteristics such as type (building vs infrastructure), size (small, medium, large), ownership (public, private) etc.
- Explore whether individual PM under one category are difficult to understand and report as compared to another.
- Test the exclusivity of the three categories from this study.

CONCLUSIONS

Industries such as manufacturing have standard lists of PM for comparison, learning and benchmarking across projects. This has not been possible in the AEC industry as there is no common vocabulary to report and share PM data. This results in project teams reinventing the wheel each time and bearing the risk of tracking sub-optimal PM which could negatively impact project performance. By creating two datasets of PM reported by 195 AEC professionals in Scandinavia and Latin America, this research contributed a feasible categorization of PM based on three key VDC elements, i.e., ICE, BIM, and PPM. A comparison of the PM categories showed that ICE PM were reported by most professionals in both the datasets, (Scandinavia: 84%, Latin America 91%), followed by PPM (Scandinavia: 68%, Latin America 79%) and BIM (Scandinavia: 30%, Latin America 91%). In addition, it operationalized VDC theory by comparing the PM categories reported. There was a disparity in the number of professionals who reported all the three PM categories (Latin America: 68%, Scandinavia:17%), indicating that there is a gap in theory versus practice of VDC, which recommends the use of ICE, BIM, and PPM together.

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REFERENCES

Belsvik, M. R., Lædre, O., & Hjelseth, E. (2019). Metrics in VDC Projects. *Proc. 27 the Annual Conference of the International. Group for Lean Construction (IGLC).*

Carley, K. (1990). Content analysis. http://casos.cs.cmu.edu/publications/papers/carley_1990_contentanalysis.PDF

Fischer, M., Reed, D., Khanzode, A., & Ashcraft, H. (2014). A simple framework for integrated project delivery. *Proceedings of the 22nd Annual Conference of the International Group for Lean Construction*, 1319–1330.

Fosse, R., & Ballard, G. (2016). Lean design management in practice with the last planner system. *Proceedings of the 24th Annual Conference of the International Group for Lean Construction, Boston, EE. UU*.

Gao, J. (n.d.). A Characterization Framework to Document and Compare BIM Implementations on Construction Projects [Ph.D., Stanford University].

Gunasekaran, A., Patel, C., & Tirtiroglu, E. (2001). Performance measures and metrics in a supply chain environment. *International Journal of Operations & Production Management*, *21*(1/2), 71–87. https://doi.org/10.1108/01443570110358468

Haugstvedt, O. H. (2019). Metrics development strategy for VDC in Design management [Master's Thesis]. NTNU.

Khanzode, A., Fischer, M., & Reed, D. (2011). Challenges and benefits of implementing Virtual Design and Construction technologies for coordination of mechanical, electrical, and plumbing systems on a large healthcare project. *Center for Integrated Facility Engineering, Stanford University*.

Khanzode, A. R. (2011). An Integrated Virtual Design and Construction and Lean (IVL) Method for Coordination of Mechanical, Electrical and Plumbing (MEP) Systems [Ph.D., Stanford University]. *Retrieved May 24, 2022, from https://www.proquest.com/docview/2451876778/abstract/AF35190AD6A5415BPQ/1*

Kunz, J., & Fischer, M. (2012). Virtual design and construction: Themes, case studies and implementation suggestions. *Center for Integrated Facility Engineering, Stanford University*.

Lavy, S., Garcia, J. A., Scinto, P., & Dixit, M. K. (2014). Key performance indicators for facility performance assessment: Simulation of core indicators. *Construction Management & Economics*, *32*(12), 1183–1204. https://doi.org/10.1080/01446193.2014.970208

Majumdar, T., Rasmussen, S. G., Del Savio, A. A., Johannesdottir, K., Hjelseth, E., & Fischer, M. (2022). A Comparative Analysis of Production Metrics across VDC Implementations. *Construction Research Congress 2022*, 1024–1033. https://ascelibrary.org/doi/abs/10.1061/9780784483978.104

Matejka, P., & Sabart, D. (2018, May 23). Categorization of clashes and their impacts on construction projects. *17th International Scientific Conference Engineering for Rural Development.* https://doi.org/10.22616/ERDev2018.17.N102

Rischmoller, L., Reed, D., Khanzode, A., & Fischer, M. (2018). Integration enabled by virtual design and construction as a lean implementation strategy. *Proc. 26th Annual Conference of the International. Group for Lean Construction (IGLC), Chennai, India.*