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A typology for describing and assessing Visual Management in construction projects

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A TYPOLOGY FOR DESCRIBING AND ASSESSING VISUAL MANAGEMENT IN CONSTRUCTION PROJECTS

Thesis presented to the Postgraduate Program in Civil Engineering: Construction and Infrastructure at the Universidade Federal do Rio Grande do Sul, in fulfillment of the requirements for the Doctor Degree in Engineering

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This doctoral thesis was assessed regarding the requirements to obtain the title of DOCTOR IN ENGINEERING, research area Construction. Its final form was approved by the Supervisor Professor and the Postgraduate Program in Civil Engineering: Construction and Infrastructure at the Universidade Federal do Rio Grande do Sul.

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To my beloved family.

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"I know that I know nothing."

(Socrates)

ABSTRACT

BRANDALISE, F. M. P. **A typology for describing and assessing Visual Management in construction projects.** 2023. Thesis (Doctor in Engineering) - Postgraduate Program in Civil Engineering: Construction and Infrastructure, Engineering School, Universidade Federal do Rio Grande do Sul, Porto Alegre, 2023.

Visual Management (VM) is a strategy for making information clear and accessible, strongly related to the lean production principle of increasing process transparency. VM also presents a very important role in promoting effective communication and seamless collaboration among team members. It is not an end but consists of practices that improve production system performance. VM practices include both VM devices (the observable portion of a managerial system) and the non-visual work involved in producing information. VM system is a set of interconnected practices deliberately designed to facilitate information sharing. This set of practices must be complementary and have common purposes, which increases the impact of VM, in comparison to isolated VM practices. Therefore, VM seems to be particularly useful for supporting the management of construction projects that can be considered a complex sociotechnical system, in which many dynamically interacting elements combined with their wide diversity may cause unanticipated variability and asset resilience. Several studies about VM in construction have been developed. However, instead of being based on a sound theoretical basis, VM tends to be implemented in construction projects mostly through efforts made by trial and error, many times only copying applications from other contexts such as manufacturing. Hence, there is a need to broaden the development of theory building related to VM. Moreover, it is also important to find innovative ways of disseminating related concepts by active methodologies, such as serious games. The aim of this thesis is to propose a typology for describing and assessing VM in construction projects. Design Science Research is the methodological approach adopted in this investigation, which is based on three academic papers. The first paper develops the first version of the typology, extending the contribution of taxonomies previously proposed in the literature, by emphasizing the role of collaboration and communication, as well as the need to integrate VM practices into managerial routines and other practices. The second paper is focused on a serious game, named VM Game. It is a tool for learning and discussing a set of VM taxonomies regarding purposes, the role of communication, the role of collaboration, and requirements. The third paper devises some propositions to explain the role and impact of VM systems in construction projects, highlighting their purpose and how they support dealing with complexity. Therefore, the typology could be refined to a final version, with ten types of analysis divided into three main levels, from a lower to a higher level of complexity and context-dependence: VM device, practice, and system. The target audience for using the artifacts devised in this investigation is the academic community interested in advancing the prescriptive knowledge on VM, besides construction companies that use VM as a strategy for information management.

Keywords: Visual Management. Typology. Construction projects.

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LIST OF ACRONYMS

EE: Escola de Engenharia

NORIE: Núcleo Orientado para a Inovação da Construção

PPGCI: Programa de Pós-Graduação em Engenharia Civil: Construção e Infraestrutura

UFRGS: Universidade Federal do Rio Grande do Sul

VM: Visual Management

CSS: Complex Sociotechnical Systems

CONTENTS

1 INTRODUCTION

This chapter introduces the theme of Visual Management in construction. It presents the gap in knowledge and the practical problem that were the point of departure for this research study. A set of research questions and objectives are stated, and then the structure of the thesis is presented.

1.1 CONTEXT

Managing any organization requires coordination and communication among people (LENGLER; EPPLER, 2007). Regarding the management of construction projects, additional challenges arise due to the peculiarities and complexity inherent to this context (KOSKELA, 1992). Construction projects can be considered complex sociotechnical systems (CSS). Those systems usually have a large number of elements (CARAYON, 2006), adaptive capacity (KURTZ; SNOWDEN, 2003), nonlinear interactions (PERROW, 1984; SNOWDEN; BOONE, 2007), emergent properties (ÉRDI, 2008), and feedback loops (ÉRDI, 2008; PERROW, 1984). Moreover, they are tightly interconnected environments involving different people and technologies, dynamic work circumstances, and flexible demands (PATRIARCA *et al.*, 2020). Therefore, considering a construction project as a CSS means that many dynamically interacting elements combined with their wide diversity may cause unanticipated variability (SAURIN; GONZALEZ, 2013). By contrast, these characteristics can also be an asset for resilience (SAURIN; GONZALEZ, 2013). Resilience is the intrinsic ability of a system or organization to adjust its functioning before, during, or following changes to sustain required operations under both expected and unexpected conditions (HOLLNAGEL, 2014).

A prescription for managing CSS such as construction projects is to give visibility to processes and outcomes, i.e., systems should make problems and complexity visible (SAURIN; ROOKE; KOSKELA, 2013). This visibility could be obtained through Visual Management (VM), as it is a sensory strategy for making information clear and accessible (TEZEL; KOSKELA; TZORTZOPOULOS, 2016). The correct representation of information for a given purpose can deal with the complexity of production systems, even in complex and unpredictable production environments (KURTZ; SNOWDEN, 2003).

VM supports the quick detection of failures and the promotion of improvements in the production system performance, not being an end in itself (TEZEL; KOSKELA; TZORTZOPOULOS, 2016; VALENTE; BRANDALISE; FORMOSO, 2019). It is strongly related to one of the Lean Production (LP) principles proposed by Koskela (1992), named "increase process transparency". Process transparency can be defined as the ability of a production process (or its parts) to communicate with people and make the production process observable to facilitate control and promote continuous improvement (FORMOSO; DOS SANTOS; POWELL, 2002). Three different dimensions were identified for transparency: (i) normative, which enables communication; (ii) formative, which enables learning; and (iii) participative, which enables collaboration (LOMBA; SANTOS, 2020).

Besides increasing process transparency, some VM purposes have been pointed out in the literature: supporting continuous improvement (BERNSTEIN, 2012; BRADY *et al.*, 2018; EAIDGAH *et al.*, 2016); contributing to the reduction of variability and the elimination of non-value-adding activities (FORMOSO; DOS SANTOS; POWELL, 2002; KOSKELA; TEZEL; TZORTZOPOULOS, 2018); and mitigating problems related to the management of complex production systems (VIANA *et al.*, 2014). A purpose is the main goal of a VM practice, and it is also named in the literature as function (TEZEL; KOSKELA; TZORTZOPOULOS, 2009), or objective (LINDLÖF, 2014).

VM also presents a very important role in promoting effective communication (KATTMAN *et al.*, 2012). In fact, VM enables a faster and more reliable approach to communication, contributing to the reduction of cycle time and variability, which highlights its importance in LP systems (KOSKELA; TEZEL; TZORTZOPOULOS, 2018). VM allows sharing the right information on time, i.e., to communicate appropriately (VALENTE; BRANDALISE; FORMOSO, 2019). Besides that, VM has another role contributing to seamless collaboration among team members (EPPLER; BRESCIANI, 2013; EWENSTEIN; WHYTE, 2007), e.g., at planning and control meetings (VIANA *et al.*, 2014). In collaborative workplaces, a combination of disposed people, processes, and artifacts like VM devices interact (NICOLINI, 2007; NIKAS; POULYMENAKOU; KRIARIS, 2007).

In order to achieve purposes, some requirements are necessary, i.e., functions, attributes, and characteristics that a product or service must perform, produce, or supply to meet the project and client needs or objectives (DICK, 2004). In VM, different requirements have been discussed in the literature, such as flexibility, which is related to the possibility of making changes in VM devices (BARTH; FORMOSO, 2021), and simplicity, which can be connected to the use and functioning of a VM device (SAURIN; FORMOSO; CAMBRAIA, 2006). Hence, VM can be especially useful in construction sites, as these environments are often large and dynamic, where multiple teams move continuously, the layout undergoes several changes throughout time work, and the construction itself can become a visual barrier (FORMOSO; DOS SANTOS; POWELL, 2002).

VM practices include both VM devices (the observable portion of a managerial system) and the non-visual work involved in producing information fields (NICOLINI, 2007). Indeed, VM requires a certain amount of work that supports what is visible but often remains hidden, i.e., managerial tasks such as devising improvement measures and producing up-to-date information (NICOLINI, 2007). Therefore, VM practices are concerned with social processes associated with the recurrent pattern of socially sustained action, i.e., practices that go beyond the idea of routine, as suggested by Gherardi (2009). A VM system is a set of interconnected practices deliberately designed to facilitate information sharing (GALSWORTH, 1997). This set of practices must be complementary and have common purposes, which increases the impact of VM, in comparison to isolated VM practices (ZANI, 2021).

According to Murata (2021), a VM system can be described through a block diagram in which the difference between the output data and the input data is the error, and variations in management resources (humans, materials, machines, etc.) create disturbances to the production system as a controlled object. The VM system determines a manipulated variable that minimizes the error and is an input to the production system (MURATA, 2021). Therefore, VM systems can support communication between people and the production systems they manage (MURATA, 2021).

VM as a strategy happens when VM is widely adopted in the company based on the organization's objectives and missions (ZANI, 2021). As Galsworth (1997, 2005) pointed out, the VM strategy encompasses plans and decisions about the sectors in which VM will be used, which VM practices will be devised (considering the purpose), and how they will be designed (considering requirements), controlled, maintained and improved. It also includes how the VM practices will be linked with other systems or goals, how people will be trained and encouraged to adopt VM, and how new VM ideas from people will be captured and disseminated (GALSWORTH, 1997, 2005).

1.2 RESEARCH PROBLEM

Several studies about VM in construction have been developed in the last decade, mostly focused on improving transparency in planning and control (BRADY, 2014), understanding VM benefits (TEZEL; AZIZ, 2017b), exploring the potential synergy between VM and digitalization (TEZEL; AZIZ, 2017a), and prescribing a model of how to devise VM systems (VALENTE; BRANDALISE; FORMOSO, 2019). However, instead of being based on a sound theoretical basis, VM tends to be implemented in construction projects mostly through efforts made by trial and error, many times only copying applications from other contexts such as manufacturing (KOSKELA; TEZEL; TZORTZOPOULOS, 2018). Previous studies have not explored the development of typologies for describing and assessing the scope and purpose of VM in construction projects. Both taxonomies and typologies could support understanding and analyzing complex fields, contributing to theory building related to VM (NICKERSON; VARSHNEY; MUNTERMANN, 2013). Taxonomies empirically categorize practices by similarity (BAILEY, 1994), while typologies represent a classification of concepts considering many dimensions (SMITH, 2002), organizing knowledge (GLASS; VESSEY, 1995).

As VM has been implemented as a very practical approach, it is also important to find innovative ways of disseminating related concepts, principles, and practices. Active methodologies, such as serious games, are an alternative, as they encourage learners to self-construct meanings through relevant learning activities (SASAKI; MÄLLINEN, 2018). Serious games are a useful tool for the construction industry because they transfer knowledge in a clear, realistic, and simple manner (HAMZEH *et al.*, 2017), serving a critical role in bridging the gap between theory and practice (BHATNAGAR *et al.*, 2022).

Hence, there is a need to broaden the development of theory building related to VM in construction projects, which must be considered CSS, i.e., a background context that presents challenges due to its complexity. It is especially important to explore VM as a system of integrated VM practices, by focusing on understanding VM purposes (functions or objectives) and which VM requirements are needed, i,e., which qualities of VM practices can support achieving their purposes. It is also necessary to extend the contribution of taxonomies previously proposed in the literature to assess the implementation of VM practices and use this typology as a learning tool, supporting the building of the VM theoretical body of knowledge. Finally, there is the need to effectively prescribe how to explain the role and impact of VM systems through propositions. This doctoral thesis is a continuation of the author's master dissertation, whose objective was to develop a method to evaluate the VM systems for production management in construction. Revisited data on VM practices from that previous study was the departure point of this investigation[1].

1.3 RESEARCH QUESTIONS

Based on the contextualization and the research problem presented, the main question to be answered by this doctoral thesis is:

How can VM taxonomies be used to describe and assess the implementation of VM practices through a typology?

In order to answer the main question, the following specific questions were proposed:

- How can a VM typology be used as a learning and discussing tool?
- How can VM systems impact production management in construction?

1.4 RESEARCH OBJECTIVES

The main objective of this doctoral thesis is:

Propose a typology for describing and assessing VM in construction projects.

The specific objectives of this doctoral thesis are:

- Extend the contribution of taxonomies previously proposed in the literature, by emphasizing the role of collaboration and communication, as well as the need to integrate VM practices into managerial routines and other practices;

[1] Part of the investigation period took place during the COVID-19 pandemic. During the following crisis, construction projects had to cope with problems such as workforce shortages, business shutdowns, disruptions in supply chains, and the introduction of new practices to protect workers' health (DOBRUCALI *et al.*, 2022; JONES; GIBB; CHOW, 2022).

- Propose a serious game for learning and discussing a set of VM taxonomies regarding purposes, the role of communication, the role of collaboration, and requirements;
- Devise propositions to explain the role and impact of VM systems in construction projects.

1.5 STRUCTURE OF THE THESIS

This doctoral thesis is divided into six chapters: (1) introduction, (2) research method, (3 to 5) three journal papers, and (6) conclusion. Chapter 1 addresses the context, research problem, questions, and objectives. Chapter 2 contains an overview of the research method, including the strategy adopted in this investigation and its design. The development of the thesis was divided into three journal papers. Paper I, presented in Chapter 3, proposes the development of a typology for understanding VM concepts and their relationships. Paper II, presented in Chapter 4, proposes a serious game for learning and discussing a set of VM taxonomies, resulting in the development of conceptual contributions. Paper III, presented in Chapter 5, suggests a set of propositions to explain the role and impact of VM systems in construction projects. Finally, Chapter 6 presents an overview of the research contributions including a refined and final version of the proposed typology, limitations of the thesis, and suggestions for future work.

2 OVERVIEW OF THE RESEARCH METHOD

This chapter presents an overview of the research method, including the research strategy and the research design.

2.1 RESEARCH STRATEGY

Design Science Research (DSR) is the methodological approach adopted in this investigation. In this approach, a solution concept, named artifact, is devised for classes of problems (LUKKA, 2003), also resulting in the development of new knowledge (VAN AKEN, 2004). Its starting point is usually the practical problem that needs to be framed and connected to existing theories (LUKKA, 2003). In DSR, the construction of knowledge and the applicability of the artifact is bounded to a limited range of situations (HEVNER *et al.*, 2004). This approach usually requires strong cooperation between academics and representatives of companies involved in empirical studies (DA ROCHA *et al.*, 2012).

DSR is prescriptive and often multidisciplinary, seeking to solve relevant context-complex problems (MARCH; SMITH, 1995). Therefore, it has been largely applied in many fields of knowledge, such as medicine (KASANEN; LUKKA; SIITONEN, 1993), information technology (MARCH; SMITH, 1995), operations management, management, engineering, information systems (HOLMSTRÖM; KETOKIVI; HAMERI, 2009).

The choice of DSR for this investigation is justified by several factors. On the one hand, the need for cooperation between the researcher and the organizations of empirical studies to solve practical problems related to the lack of transparency in construction sites. On the other hand, as VM has been mainly implemented in construction projects by practitioner efforts (KOSKELA; TEZEL; TZORTZOPOULOS, 2018), there is also an opportunity to contribute prescriptively by developing artifacts that can support the building of the VM theoretical body of knowledge. An artifact can be considered as an interface between an internal environment (the organization of the artifact itself) and an external environment where it operates (DRESCH; LACERDA; JUNIOR, 2015).

March and Smith (1995) suggested four categories of artifacts: constructs, models, methods, and instantiations. Constructs are the vocabulary within a domain composed of terms that characterize problems and describe possible solutions. Models are a set of propositions and expressions that relate constructs for describing situations, problems, or solutions through a framework. Methods are steps to perform a task targeting a goal, usually associated with how to apply constructs and models. Instantiations are implementations of constructs, models, and methods, demonstrating the feasibility of the conceptual elements of the built solution (MARCH; SMITH, 1995).

Besides that, DSR can result in design principles and propositions. Design principles are concepts that guide design, i.e., suggestions for action in a given circumstance aiming for an effect (VAISHNAVI; KUECHLER, 2015). Propositions are testable hypotheses generalized to the research field (KUECHLER; VAISHNAVI, 2012). Therefore, an untested technological rule can be seen as a preliminary design proposition, i.e., a preliminary hypothesis explaining the behavior of one or more dependent variables in terms of the behavior of an independent one (VOORDIJK, 2009).

The main contribution of this investigation is a typology for describing and assessing VM in construction projects. The typology can be considered a type of conceptual model. It was refined and improved during the thesis development by the contributions of the other artifacts explored: a serious game and a set of propositions. The serious game is an instantiation of the proposed typology, since it allowed to operationalize and test some of its aspects. The propositions emerged inductively from only one empirical study, being considered preliminary design propositions with a prescriptive character. The target audience for using the artifacts is the academic community interested in advancing the prescriptive knowledge on VM, besides construction companies that use VM as a strategy for information management.

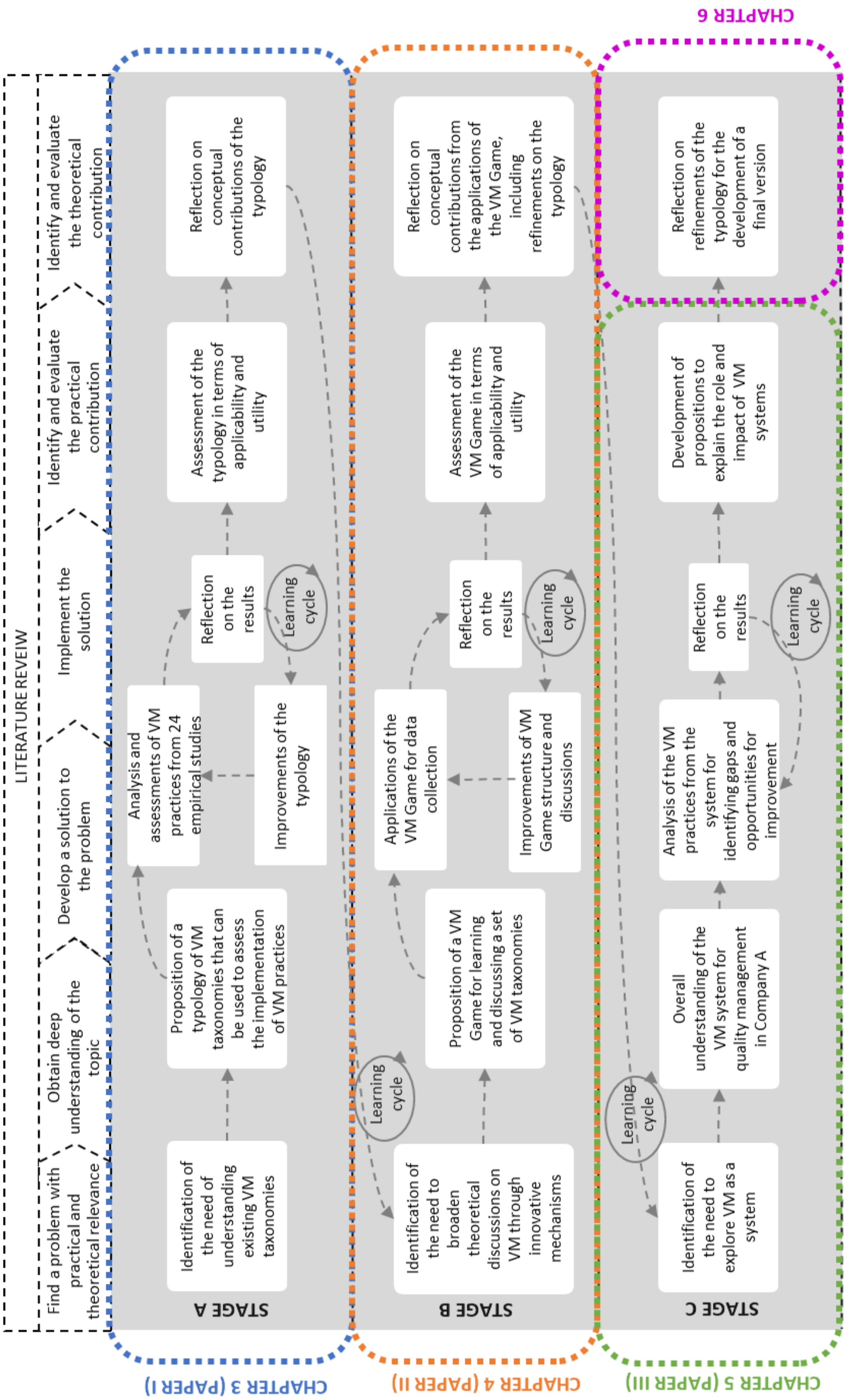
2.2 RESEARCH DESIGN

Figure 1 provides an overview of the research design carried out in this investigation. It is divided into three stages: A, B, and C. Each stage contains six main steps of a DSR process, based on Kasanen, Lukka, and Siitonen (1993) and Lukka (2003): (1) to find a problem with practical and theoretical relevance; (2) to obtain a deep understanding of the topic; (3) to develop a solution to the problem; (4) to implement the solution that has the potential for practical and theoretical contributions; (5) to identify and evaluate the practical contribution of the solution; (6) to identify and evaluate the theoretical contribution of the solution. Usually, in DSR, the research process is not linear and includes iterations among the steps (VAISHNAVI; KUECHLER, 2007). Therefore, learning cycles of reflection and refinement of the VM typology were carried out inside and between stages A, B, and C for developing and improve this main artifact of the investigation. Moreover, a literature review has supported all the research work.

In Stage A, a theoretical exploration of existing VM taxonomies proposed in the literature was made. Based on that, an initial version of the typology for assessing the implementation of VM practices in production systems was devised. This first version of the typology considered only some VM taxonomies existing in literature (e.g., GALSWORTH, 1997; BITITCI; COCCA; ATES, 2015; TEZEL et al., 2015). Through reflection on the results of analysis from 24 empirical studies in CSS located in the State of Rio Grande do Sul, Brazil (16 sites of construction companies and 8 production lines of the manufacturing industry[2]), the typology was improved and refined for assessing the 118 VM practices identified. Taxonomies related to communication, collaboration, and integration into managerial routines and other practices were added to the typology, which was evaluated in terms of applicability and utility. This VM typology has a prescriptive character and it can be used for two functions: (1) to guide the development or implementation of VM in construction sites, and (2) to assess the degree of maturity of the VM that has been implemented.

[2] Empirical studies in manufacturing companies were undertaken as a benchmarking exercise, as this kind of CSS has been historically more developed than construction in the implementation of VM.

Figure 1 – Research design



Source: author.

In Stage B, the need to broaden the theoretical discussions on VM through innovative mechanisms was identified. Then, a serious game named VM Game was proposed. As an active learning tool, it uses examples of VM practices from CSS to discuss a set of VM taxonomies embedded in the VM typology that were chosen by their relevance as they involved both the visual and non-visual work of VM practices: purposes, the role of communication, the role of collaboration, and requirements. Six initial exploratory applications of the game allowed its improvement in terms of structure and discussions. Thirteen applications of the final version of the VM Game were undertaken for data collection: six VM practices were discussed by 230 people who attended the sessions, including specialists in VM. Applicability and utility were the two constructs used to assess the VM Game. Moreover, insights for conceptual contributions emerged from the application of VM Game, including opportunities for refinement of the typology previously developed in Stage A.

In Stage C, an empirical study was carried out in a residential construction site of Company A, a leading company in Brazil in implementing lean production concepts and practices, including VM. The unit of analysis of the empirical study was the VM system for quality management, a core dimension of production management. Analysis of the set of practices involved in the VM system allowed the identification of gaps and improvement opportunities. Finally, a set of preliminary design propositions to explain the role and impact of VM systems in construction projects was devised, highlighting their purposes and how they support coping with complexity. Then, some refinements in the proposed typology could be suggested for developing its final version.

Each research stage resulted in one academic paper describing the empirical studies that supported this investigation, the sources of evidence, and the partial contributions. The papers independently present the outcomes of sequential activities, corresponding to specific research objectives, as summarized in Table 1. The main artifact, developed in this investigation, i.e., the proposed typology is the result of the thesis as a whole.

Table 1 – Research stages outcomes

	Paper I	Paper II	Paper III
Paper title	Development of a typology for understanding Visual Management concepts and their relationships	Visual Management in construction projects: discussing concepts and practices through a serious game	Explaining the role and impact of visual management systems: empirical study in a construction project
Specific Research Objectives	Extend the contribution of taxonomies previously proposed in the literature, by emphasizing the role of collaboration and communication, as well as the need to integrate VM practices into managerial routines and other practices.	Propose a serious game for learning and discussing a set of VM taxonomies regarding purposes, the role of communication, the role of collaboration, and requirements.	Devise propositions to explain the role and impact of VM systems in construction projects.

Source: author.

3 DEVELOPMENT OF A TYPOLOGY FOR UNDERSTANDING VISUAL MANAGEMENT CONCEPTS AND THEIR RELATIONSHIPS (PAPER I)

Authors: Fernanda Marisa Pasinato Brandalise, Carlos Torres Formoso, and Daniela Dietz Viana

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4 VISUAL MANAGEMENT IN CONSTRUCTION PROJECTS: DISCUSSING CONCEPTS AND PRACTICES THROUGH A SERIOUS GAME (PAPER II)

Authors: Fernanda Marisa Pasinato Brandalise, Carlos Torres Formoso, and Daniela Dietz Viana

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5 EXPLAINING THE ROLE AND IMPACT OF VISUAL MANAGEMENT SYSTEMS: EMPIRICAL STUDY IN A CONSTRUCTION PROJECT (PAPER III)

Authors: Fernanda Marisa Pasinato Brandalise, Carlos Torres Formoso, and Daniela Dietz Viana

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6 CONCLUSION

This chapter presents the final version of the typology for describing and assessing VM in construction projects, the main objective of this doctoral thesis. It also concludes the thesis by highlighting its contributions and limitations, besides suggesting topics for future research on the application of VM in construction.

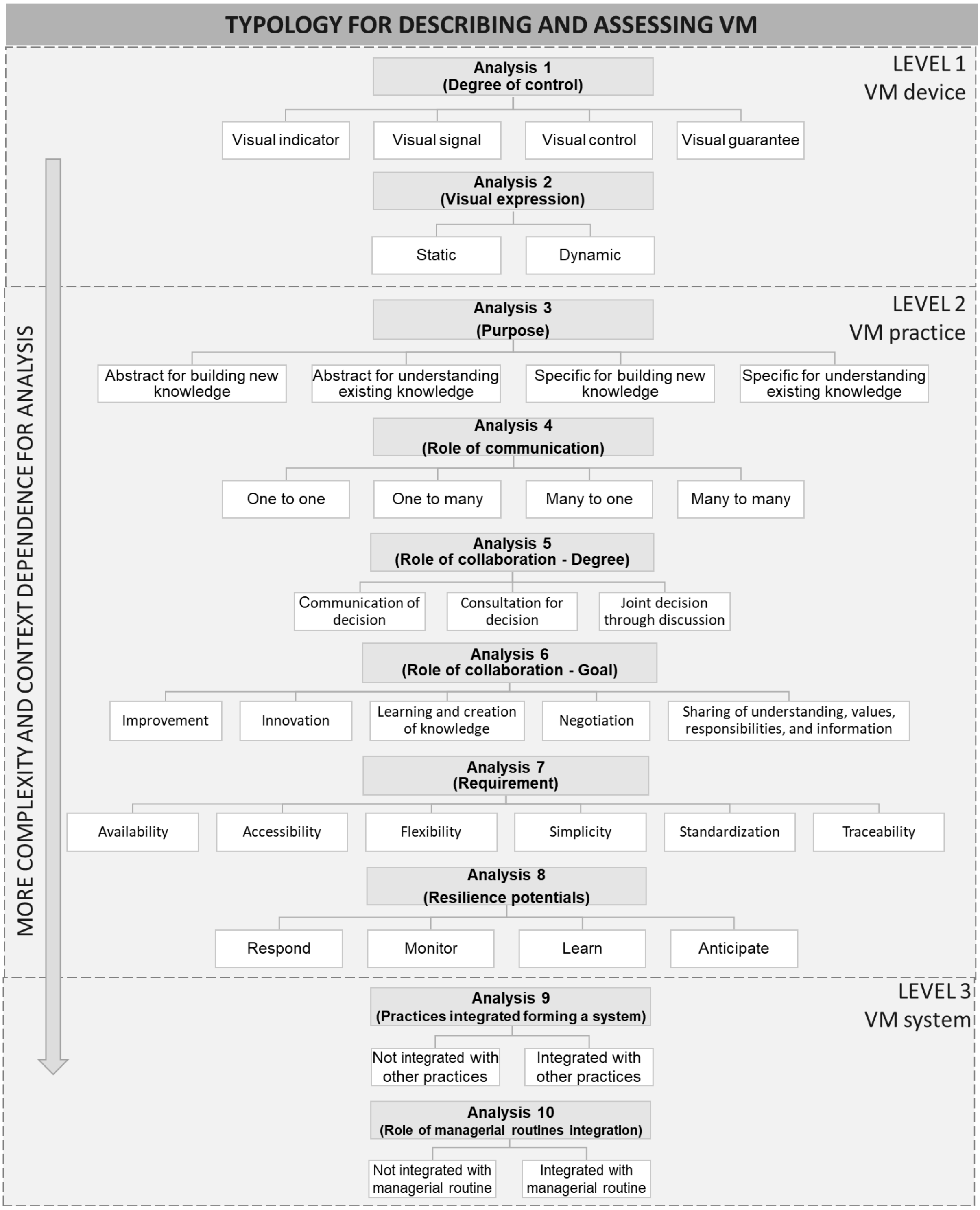
6.1 FINAL VERSION OF THE TYPOLOGY

Theoretical contributions from the VM Game (Chapter 4) and the set of preliminary design propositions devised (Chapter 5) have contributed to refining the typology developed in Chapter 3. It resulted in the final version of the typology for describing and assessing VM in construction projects, the artifact presented in Figure 2.

The typology is based on ten types of analysis that are divided into three main levels, from a lower to a higher level of complexity and context-dependence: VM device, practice, and system. Analyses 1, 2, 4, 5, 8, 9, and 10 can be considered taxonomies presenting categories mutually exclusive and collectively exhaustive, i.e., there is no overlapping between categories definitions, as suggested by Nickerson, Varshney, and Muntermann (2013) and Bailey (1994). Analyses 3, 6, and 7 present categories that guide the user to understand the VM practice but are limited to a set of examples identified in the literature that could be extended.

Level 1 corresponds to the lowest level of complexity, in which only the visual part of the practice is analyzed. At this level, VM devices are classified in Analysis 1 as indicators, signals, controls, or visual guarantees according to the degree of control proposed by Galsworth (1997). In Analysis 2, devices are classified according to their form of visual expression (i.e., static or dynamic device), as suggested by Bititci, Cocca, and Ates (2015). Both taxonomies were explained and explored in Chapter 3.

Figure 2 – Final version of the typology



Source: author.

Level 2 is concerned with VM practices, i.e., both the visual and non-visual work involved, and is comprised of Analyses 3 to 8. Analysis 3 refers to the purpose of the practice, i.e., its goals, functions, or objectives. The main function of the practice was already explored in the first version of the typology presented in Chapter 3 through closed categories that were similar to the ones proposed by Tezel et al. (2015): control (used as a control device); guide (used as an execution procedure); establish goals (used as a target specification); supply (used as support to material supply); or display a prototype. However, a wide range of purposes can be identified for a practice, considering the context of use. Therefore, the closed options were replaced by four classes in which a range of purposes of a VM practice can be categorized, as it was explored in the discussion of the VM Game (Chapter 4): abstract purposes for building new knowledge, such as "increase process transparency"; abstract purposes for understanding existing knowledge, such as "simplify"; specific purposes for building new knowledge, such as "planning"; and specific purposes for understanding existing knowledge, such as "training". The analyses of purposes were delimited to abstract and specific classes for the VM practices identified in the empirical study of Chapter 5.

Analysis 4 is concerned with the role of communication, considering who is the sender and the receiver of the information displayed in a VM practice. Four categories have been defined and explained in Chapter 3, and explored in the VM Game (Chapter 4) and in the empirical study (Chapter 5): one to one; one to many; many to one; or many to many. Analysis 5 and 6 refer to the role of collaboration in VM. In Chapter 3 practices were only dichotomously classified as either not collaborative, or collaborative, considering how much a VM practice promotes discussion among users, especially during managerial meetings. The literature review during the VM Game development (Chapter 4) has allowed to extend the role of collaboration to analyze the degree and goals of collaboration, which was also explored in the empirical study (Chapter 5). Regarding Analysis 5, three classes were proposed for the degree of collaboration: communication of decision; consultation for decision; or joint decision through discussion. In Analysis 6, many goals of collaboration can be identified in a VM practice, such as improvement; innovation; learning and creation of knowledge; negotiation; and sharing of understanding, values, responsibilities, and information.

Analysis 7, regarding the requirements of a VM practice, was explored in the VM Game (Chapter 4) considering the ones suggested by Pedó *et al.* (2022) for VM systems that support civil engineering design management: availability; accessibility; flexibility; simplicity; standardization; and traceability. Although many other requirements have been proposed in the literature, the set selected for the typology was limited for simplification, in order to be applicable in a serious game. Even so, they fit into the context of construction projects, and a

VM practice may have several different requirements for achieving its purposes, as was pointed out in the empirical study reported in Chapter 5.

Analysis 8 considers the resilience potentials proposed by Hollnagel (2009): to respond to events effectively and flexibly; to monitor system performance and changes in the environment; to anticipate developments threats and opportunities; and to learn from the experience of past failures and successes. As was explored in the empirical study reported in Chapter 5, practices that fulfill resilience potentials are key elements in the managerial paradigm for dealing with complexity in CSS.

Level 3 involves the highest level of complexity and context dependence. Analysis 9 is concerned with the combination of distinct VM practices that may form a VM system, which can potentially have a much stronger impact than isolated visual devices or practices. Finally, Analysis 10 is concerned with whether the VM practices are integrated into managerial routines, which tends to increase the effectiveness of purposes. Both Analyses 9 and 10 were proposed in Chapter 3 and explored in Chapter 5.

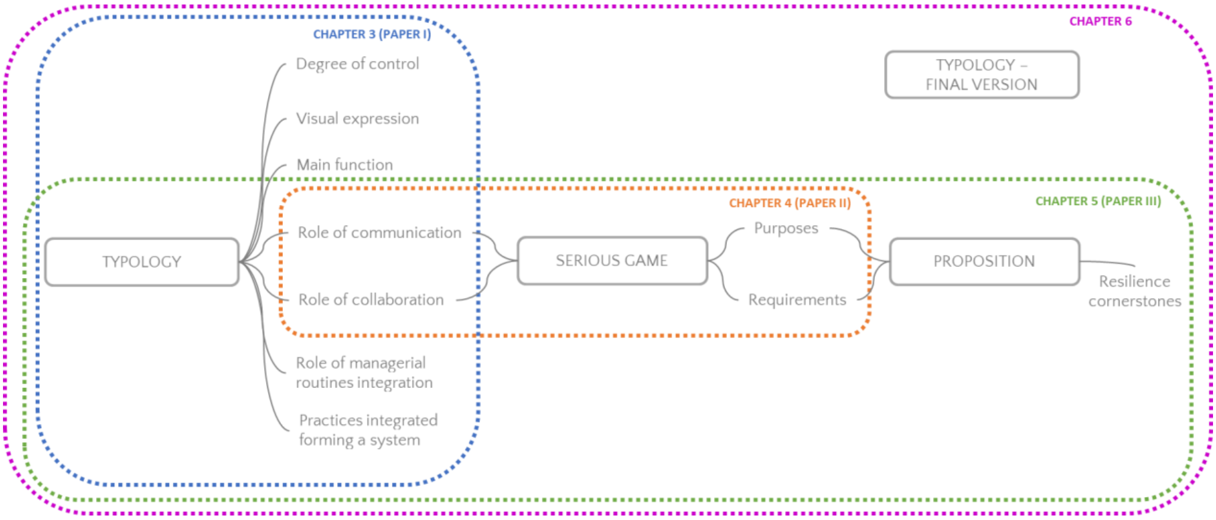
6.2 CONTRIBUTIONS AND LIMITATIONS

The point of departure of this investigation was the gap in the literature concerning the need to broaden the development of theory building related to VM in supporting production management in construction projects. Similarly to other LP concepts, VM has been mainly implemented through trial-and-error efforts. Moreover, the challenge to create innovative mechanisms for disseminating and discussing concepts and practices related to VM among practitioners and academics was identified. Exploring VM as a system of integrated VM practices in construction projects was considered to be particularly relevant for the development of the VM theoretical body of knowledge.

The main objective of this doctoral thesis was to devise a typology for describing and assessing VM in construction projects. The specific objectives have encompassed: (1) extending the contribution of taxonomies previously proposed in the literature; (2) developing a serious game for learning and discussing a set of VM taxonomies; and (3) devising propositions to explain the role and impact of VM systems in construction projects. A set of constructs related to the VM were explored by contributions of the thesis in Chapters 3, 4, and 5 (respectively, Papers I, II, and III), aiming to refine and improve the typology, whose final version is presented in Chapter 6

(Figure 2). It has happened successively through the thesis development and the relationship among them are summarized in Figure 3. The final version of the typology has not been assessed yet, which is a limitation of this investigation.

Figure 3 – Contributions of the thesis



Source: author.

The first version of the typology was presented in Chapter 3, which suggests three possible units of analysis, VM devices, practices, or systems. The initial version of the typology emphasizes the role of collaboration and communication, as well as the need to integrate VM practices into managerial routines and other practices, extending the contribution of taxonomies previously proposed in the literature. It can be used as an analytical framework to assess the implementation of VM practices. As a secondary contribution, the proposed typology was used to identify the profiles of VM practices adopted in a sample of construction sites and to identify improvement opportunities for the construction industry.

The assessment of the typology was based on constructs of applicability and utility. Regarding applicability, the typology is represented by an easy-to-understand hierarchical structure that can be easily expanded by developing further research related to the taxonomies of VM. In terms of utility, the typology can be used to assess the degree of maturity of VM practices, to identify gaps in the VM practices adopted in production systems, and to make comparisons between different production systems from the same sector, or as a support to benchmarking exercises.

This first version of the typology presented some limitations. It only embraces the categories and levels of analysis that were relevant to the specific context being investigated. Moreover, it was used only to asses VM practices from production management.

Chapter 4 presents another contribution of the thesis, which is a serious game, named VM Game. The game can be used for learning and discussing a set of VM taxonomies that were chosen from the literature by their relevance: purposes, the role of communication, the role of collaboration, and requirements. Descriptions of VM practices were developed to be used in applications of the VM Game. The discussions that happened during the application of the VM game supported the development of conceptual contributions. For example, it was possible to understand the diversity of purposes and the relationships among them, besides the connections among some purposes and requirements. As a consequence, the application of the VM Game provided insights for the refinement of the typology previously devised, besides to be an instantiation that allowed to empirically test and assess it

Concerning the taxonomy of VM purposes, the conclusion was made that these are context-dependent and not limited to a set of limited categories. In terms of the communication role, its relevance was tested by enhancing the understanding of the VM practice through discussions focused on identifying who is sending and receiving information. Concerning the collaboration role, a discussion was introduced on the degree of collaboration and also the goals of the collaboration. Finally, the VM requirements can be regarded as a new analysis that can be incorporated into the existing typology, emphasizing the understanding of the necessary characteristics of visual and non-visual work associated with each VM practice.

The VM Game was also assessed according to applicability and utility constructs. In terms of applicability, the VM Game presents clear guidance for playing, simplicity in its structure, and flexibility in its use. The utility is evidenced by its relevance as a learning tool, allowing discussions among the participants, based on real examples of VM practices. Moreover, the utility is also a consequence of contributions to the VM theoretical body of knowledge. Indeed, the VM Game discussions provided theoretical insights into the VM's underlying ideas, especially in the sessions in which there were experts on VM.

Regarding the limitations of the VM Game, it must be pointed out that the taxonomies discussed through the VM Game only embrace a few categories considered the most relevant. Moreover, there was a limited number of applications of the game, which was focused on discussions of a limited set of VM practices. Therefore, the selection of other examples of VM practices and discussions among other participants could result in different analyses.

Finally, Chapter 5 proposes a set of preliminary design propositions to explain the role and impact of VM systems in construction projects, based on a empirical study in which the VM system used for quality management by a Brazilian company was analyzed. The first proposition has highlighted that a VM system is more than the sum of the VM practices, focusing on the connections among them, the users and the environment, and the complementary purposes that make the system more resilient. The potentials of VM in supporting to cope with complexity and promoting collaboration by involving users actively were also explored, besides the necessity of understanding the requirements of the system.

The propositions emerged inductively based on the analysis of the empirical study and the literature review. Although it presents a prescriptive character, it was not assessed nor used in other organizational contexts, which is a limitation of this investigation. Moreover, analysis of other VM systems than quality management could result in insights for different propositions, increasing and improving the understanding of VM systems.

6.3 SUGGESTIONS FOR FUTURE RESEARCH

Some opportunities for developing further research on VM in construction projects have been identified by this investigation:

(1) to assess the final version of the typology for describing and assessing VM in construction projects by applying it in empirical studies;

(2) to embrace other VM aspects to extend the scope of applicability of the typology, such as proximity of VM practices to where they are used, and maintainability of VM systems with fewer resources;

(3) to explore the differences among conventional, digital, and hybrid VM systems;

(4) to perform comparative studies on VM with other sectors (besides manufacturing), such as healthcare, digital technologies, oil and gas, real estate, hospitality services, etc, thus extending the benchmarking exercise for the construction industry;

(5) to apply the VM Game to other contexts and objectives, making it more self-going and aiming to explore additional insights into the typology;

(6) to evaluate and refine the set of propositions to explain the role and impact of VM systems by fully or partially implementing them in other organizational contexts.

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