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Visual Management in design management within a digital environment

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VISUAL MANAGEMENT IN DESIGN MANAGEMENT WITHIN A DIGITAL ENVIRONMENT

Dissertation presented to the Postgraduate Program in Civil Engineering of the Universidade Federal do Rio Grande do Sul as part of the requirements for the Degree of Master of Engineering

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This Master dissertation was assessed by the Board of Examiners and considered suitable for obtaining the title of MASTER IN ENGINEERING. Its final version was approved by the supervising professor and the Postgraduate Program in Civil Engineering: Construction and Infrastructure of the Universidade Federal do Rio Grande do Sul.

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À minha família,
por me ensinar que casa é onde o coração está.

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‘Learning is the only thing the mind never exhausts, never fears, and never regret’
Leonardo da Vinci

ABSTRACT

PEDO, B. **Visual Management in design management within a digital environment.** 2020. Dissertation (Master of Engineering) - Postgraduate Program in Civil Engineering of Universidade Federal do Rio Grande do Sul, Porto Alegre, 2020.

Difficulties in managing the construction design process are strongly related to its nature, as a large number of interdependent decisions are involved, which need to be made by many different stakeholders, in an environment that has a high degree of uncertainty. Moreover, there is a growing use of digital tools to support design. Traditional communication approaches used in design management only partially comply with the requirements of digital contexts, and new methods and tools are necessary to address these challenges. Visual Management (VM) has the potential to increase process transparency in the design stage, in order to support collaboration and communication and facilitate the transfer of information. However, the literature on the implementation of VM to support design management is still scarce. Moreover, there is limited understanding of the connection between VM and information and communication technologies (ICT). This investigation aims to propose a set of requirements to support VM applications for design planning and control within digital contexts, which can potentially contribute to improving the effectiveness of VM. This set of requirements were initially identified within the literature, considering different fields of knowledge, and then refined in an empirical study that was developed in collaboration with an infrastructure design and consultancy company in the UK. The secondary objectives are (i) to devise a concept map connecting different VM constructs related to design management systems and (ii) to propose guidelines for the integration of Visual Management in design management within digital environment. The Design Science Research approach was the methodological approach adopted in this investigation, which involved incremental learning cycles for devising the artefact, carried out in three different projects. The main findings include (i) the definition of a set of VM requirements that are applicable to the context investigated in this research study; (ii) an assessment of the relevance of the requirements for different types of visual practices, hierarchical planning levels, and stakeholders that are involved; (iii) the identification of some current limitations and challenges of implementing digital VM in construction design. From a practical perspective, this set of requirements may guide practitioners and academics in devising and assessing digital VM practices.

KEYWORDS: Visual Management, Digitalisation, Design Management

RESUMO

PEDO, B. **Visual Management in design management within a digital environment.** 2020. Dissertação (Mestrado em Engenharia) – Programa de Pós-Graduação em Engenharia Civil: Construção e Infraestrutura, Escola de Engenharia, Universidade Federal do Rio Grande do Sul, Porto Alegre, 2020.

As dificuldades no gerenciamento de projeto são consequência da natureza do processo de projeto, o qual envolve um grande número de decisões interdependentes, que precisam ser tomadas por diversos stakeholders, em um ambiente com um alto grau de incerteza. Além disso, há um crescente uso de ferramentas digitais para apoiar o gerenciamento de projeto. As abordagens de comunicação tradicionais usadas no gerenciamento de projeto atendem apenas parcialmente aos requisitos dos contextos digitais, e novos métodos e ferramentas são necessários para enfrentar esses desafios. A gestão visual (GV) tem o potencial de aumentar a transparência do processo de projeto, permitir melhor colaboração e comunicação e facilitar a transferência de informações. No entanto, a literatura sobre a implementação de GV para apoiar a gestão de projetos ainda é escassa, e também há uma compreensão limitada da conexão entre GV e tecnologias de informação e comunicação (TIC). O principal objetivo deste trabalho de pesquisa é propor um conjunto de requisitos para apoiar aplicações de GV para planejamento e controle de projetos em contextos digitais, que podem contribuir potencialmente na maior eficácia de GV. Esse conjunto de requisitos foi inicialmente identificado na literatura, considerando diferentes áreas do conhecimento, e posteriormente refinado em um estudo empírico desenvolvido em colaboração com uma empresa de projeto e consultoria de infraestrutura no Reino Unido. Os objetivos secundários são: (i) elaborar um mapa conceitual relacionando diferentes conceitos de GV para sistemas de gestão de projetos, e (ii) propor diretrizes para a adoção de GV em gestão de projeto considerando contextos digitais. Design Science Research foi a abordagem metodológica adotada nesta investigação, através de ciclos de aprendizagem incrementais para a concepção do artefato, os quais foram realizados em três projetos diferentes. As principais contribuições incluem (i) definição de um conjunto de requisitos de GV aplicáveis ao contexto investigado nesta pesquisa; (ii) avaliação da relevância dos requisitos para diferentes tipos de práticas visuais, níveis hierárquicos de planejamento e stakeholders envolvidos; e (iii) identificação de algumas limitações e desafios na implementação da GV digital em projeto de construção. De uma perspectiva prática, esse conjunto de requisitos pode orientar profissionais e acadêmicos na elaboração e avaliação de práticas de GV digital.

Palavras-chave: Gestão Visual, Digitalização, Gestão de Projetos

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1 INTRODUCTION

This chapter is divided into seven sections. Section 1.1 describes the practical problem which was the starting point of this investigation. Section 1.2 presents the background related to the context of this research. Section 1.3 investigates the research problem, describing the gap in knowledge identified in the literature review. Section 1.4 defines the research questions. Section 1.5 defines the research objectives. Section 1.6 explains the limitations. Section 1.7 describes the content and structure of this dissertation. This investigation is following the Design Science approach, starting from a practical problem. The understanding of the problem and the development of the solution guided the exploration of the research problem and the literature review.

1.1 PRACTICAL PROBLEM

The starting point of this investigation was a practical problem identified in an infrastructure design company, named as Company A in this research work. It is based in the UK, and provides design, consultancy, engineering, and project management services. The researcher carried out the main empirical study as part of a post graduate exchange programme between UFRGS and the University of Huddersfield.

This company operates in highways and railways design projects and has been involved in the implementation of some Lean practices and digital tools to support design management for approximately 8 years. One important element of the context of the empirical study is the high level of complexity of the design projects, due to both structural complexity (e.g. the number of parts and subsystems involved and the degree of interdependency between them), and uncertainty associated with some project management processes.

Company A has decided to implement lean practices and digital design solutions across the firm with the aim of increasing efficiency in the highways sector. However, that company was still facing some challenges related to low-productivity, limited standardisation, fragmentation and lack of quality in design processes. Therefore, information and communication technologies (ICT) and Lean practices, especially Visual Management (VM) have emerged as opportunities to deal with those issues.

The topic of digitalisation has become even more relevant nowadays, due to the Coronavirus pandemic (COVID-19) that started in 2020. In order to contain the spread of the virus, the World Health Organization (WHO) guided authorities to adopt public health and social measures, such as large-scale restrictions, which are usually referred to as lockdowns. The health of economies, organizations and individuals has been expressively impacted with the worldwide outbreak of COVID-19 (TORTORELLA et al., 2020)., Different measures have been adopted to preserve employees' health without affecting the business (TORTORELLA et al., 2020). Non-essential services have been encouraged to be carried out in home office, affecting ways of working, collaborating, and communicating.

The main company involved in this investigation had many digital technologies implemented even before the pandemic. However, due to the pandemic situation, digitalisation has become essential in different sectors, including civil engineering projects. Most interactions among design teams started to be held in virtual environments, through the adoption of several digital tools and platforms. Research on the benefits and barriers of digital visual tools in design can potentially contribute to improve communication, increase efficiency and also support the introduction of changes in design management in the post-pandemic world.

1.2 BACKGROUND

The growing complexity in design management (KOSKELA, 1992), combined with key innovations in the construction sector, have demanded major changes in traditional project management approaches. Managing stakeholders' interdependency is increasingly challenging and complex, as many of parts need to be coordinated and integrated (HOOPER; EKHOLM, 2010). New approaches and tools to increase value, reduce or eliminate waste, and support continuous improvement are needed to address such challenges (KOSKELA, 1992; SACKS; TRECKMANN; ROZENFELD, 2009), considering that the traditional communication approaches to support decision making do not meet the needs of stakeholders (HOOPER; EKHOLM, 2010).

Over the years, the understanding of project management assumptions has evolved, due to the need to improve the ability of managers to deal with different conditions (LAUFER; SHENHAR, 1996). Traditionally, the management-as-planning approach, as named by Johnston and Brennan (1996), has been pointed out as a traditional practice in construction processes (KOSKELA; HOWELL, 2002). This approach assumes that the project presents a high level of predictability and causality (VIANA, 2015), being effective to projects that have low levels of complexity (LAUFER; SHENHAR, 1996). Different approaches emerged in the following years, considering the concepts of integration, flexibility, and dynamism, as described by Laufer and Shenhar (1996). Those authors argued that the emerging methods and concepts were the result of changing project characteristics, such as complexity, uncertainty, and short lead-time. Despite the fact that those new management approaches have progressed over time, some industries continue to adopt traditional project management approaches, which neglect complexity, resulting in issues and failures regarding project outcomes (ATKINSON, 1999).

The lack of information and systems integration can affect the information transfer between stakeholders and, consequently, managerial processes, potentially increasing project overruns and rework (EASTMAN et al., 2008). The lack of accurate information to support critical decisions points can also result in delays in the design process (ZIRGER; HARTLEY, 1994). Design is a complex and iterative process and, consequently, prone to errors, requiring new methods to support it (SOUZA PINTO et al., 2014). Moreover, decision making at the design stage influences process reliability and efficiency at the construction stage (EASTMAN et al., 2008).

Lean production is a managerial philosophy that emerged in the manufacturing. It has been pointed out as an important approach to increase stakeholders' value, as well as to eliminate activities that do not add value (WOMACK; JONES; ROOS, 1991). Koskela (2000) suggested that adapting the lean philosophy to the construction industry can help to reduce rework and increase productivity, as well as support continuous improvement. The adoption of Lean Production in this sector, according to Dave, Koskela e Kiviniemi (2013), has encouraged the adoption of collaboration in the supply chain across design and construction stages, as well as the application of new planning and control approaches. Nonetheless, most studies on the implementation of Lean in construction have not focused on design management (LINDLÖF; SÖDERBERG, 2011; TRIBELSKY; SACKS, 2011). Only recently, some studies have proposed a number of design management approaches and have devised prescriptive models (HAMZEH; BALLARD; TOMMELEIN, 2009; WESZ; FORMOSO; TZORTZOPOULOS, 2018; ABOU-IBRAHIM; HAMZEH, 2019; KEROSUO et al., 2019)

The Lean philosophy has been poorly adopted in the early stages of design processes, which is described as a period where decisions have a major influence on the construction processes (EMMITT; SANDER; CHRITOFFERSEN, 2006). According to Emmitt, Sander and Chritoffersen (2006), a substantial number of problems tackled in the construction are a result of ineffective decision-making and communication in design, which can result in a degree of uncertainty for the production.

The increase of transparency is one of the core production management principles proposed by Koskela (1992), which has been introduced in manufacturing by companies that have adopted the Lean Production Philosophy. The aim of process transparency is to enable continuous and direct observations of the key processes, so operations can be better understood, and errors can be detected quickly (KOSKELA, 1992). The increase of process transparency can facilitate the development of consistent outcomes, support the autonomy and commitment of stakeholders, and simplify decision-making (MOSER; SANTOS, 2002), by enabling process control and improvement (FORMOSO; SANTOS; POWELL, 2002). By contrast, the lack of process transparency makes communication and coordination ineffective (KOSKELA; HOWELL, 2008), which tends to increase mistakes (KOSKELA, 1992).

Visual management (VM) is a managerial approach to support the increase of process transparency (FORMOSO; SANTOS; POWELL, 2002) and can be characterised essentially as an expression of visibility (GREIF, 1991). VM is a way to identify differences between the desire conditions, the patterns and unusual situations of a system, allowing the pattern to be restored as quickly as possible (OHNO, 1988). Therefore, VM can potentially allow corrective measures to be taken as soon as needed during design development. Visualisation techniques can also be used to avoid information overflow, supporting communication among diverse stakeholders and increasing the accessibility of information, as well as assist in managing ambiguity and uncertainty, which are inherent to design development (LINDLÖF, 2014).

The implementation of VM with the support of ICT can potentially facilitate the management of the design process, as information visualisation can provide support to handle uncertainty, increasing the team's information processing capability through communication (LINDLÖF, 2014). Effective information management solutions considering people, process and technologies have been explored by Laine, Allhava and Kiviniemi (2014), based on the understanding of machines and human interactions (ZHANG, 2012). Visual representations, as VM is also called, can help to maximize visual perception, potentially supporting a quick and effective communication (ZHANG, 2012), and strategic decision-making (KILLEN; KJAER, 2012).

1.3 RESEARCH PROBLEM

Design and engineering management has been often criticised for poor communication and coordination (MAGUIRE, 2019), and lack of trust (ATKINSON; CRAWFORD; WARD, 2006). Inefficiency and waste in design have been associated to the lack of measures and tools to assess value generation and the effectiveness of information flows (TRIBELSKY; SACKS, 2007). It is widely known that not enough consideration is given to design planning and control, despite the importance of the design process for the projects' success (TRIBELSKY; SACKS, 2011). Planning and control systems also have a key role by supporting project managers in the planning, communication, and coordination of the stakeholders involved, as well as contributing to measure and evaluate performance (LAUFER; SHENHAR, 1996).

The lack of successful project planning and control systems has been pointed out in the literature as a central reason for time and cost overruns (LI; TAYLOR, 2014; LAUFER et al., 2015). In practice, design planning and control is often limited to producing a list of design deliverables defined at the beginning of each design stage (CHOO et al., 2004). Choo et al. (2004) argues that design planning and control should be based in the flow of information, instead of deliverables. Considering that design activities are interrelated, it is challenging to find an appropriate sequence that reduces rework, especially considering the limitations of current project management software, which are based on the traditional project management approaches (CHOO et al., 2004).

The Last Planner System (LPS) was developed in the 1990s as an alternative to traditional planning systems (BALLARD; HOWELL, 1998), which is based on Lean Production principles (GONZÁLEZ; ALARCÓN; MUNDACA, 2007). LPS has been successfully implemented in the design process (BALLARD; HAMMOND; NICKERSON, 2009; HAMZEH; BALLARD; TOMMELEIN, 2009;

HANNELE KEROSUO et al., 2019), integrating planning and control between different managerial levels and processes (WESZ; FORMOSO; TZORTZOPOULOS, 2018). However, there seems to be gaps in design planning and control, such as the need to increase transparency and the collaboration and involvement of team members in planning and control (TZORTZOPOULOS; FORMOSO; BETTS, 2001; DANIEL et al., 2017), as well as the need to create LPS performance metrics to assess the design process (HAMZEH; BALLARD; TOMMELEIN, 2009). There are also difficulties in analysing the VM scenario as a whole in management processes and understanding how visual tools are implemented at all hierarchical levels and connected to each other, as suggested by Greif (1991) and Brandalise (2018).

The literature has highlighted that there are few studies exploring the implementation of VM in design, even though VM practices have already been adopted to support design management (TEZEL, 2011; TJELL; BOSCH-SIJTSEMA, 2015). In contrast, there are many examples of visual management in construction, however, they are limited to isolated applications that have not been implemented systematically (BRADY et al., 2018). In fact, previous research studies have not addressed visual management from a broader perspective, being focussed on some specific tools (TEZEL et al., 2015). The visual tools are also approached intuitively and based on common sense (BEYNON-DAVIES; LEDERMAN, 2017). Nicolini (2007) argues it is essential to understand the visual tools adopted considering the interconnections between people and process, considering that the visual practices are part of a complex combination of human and non-human elements working together. So, there is a need to further understand the integration of VM tools in the design process.

Emerging information and communication technologies can be used to support collaborative practices in the design process, by enabling the integration of multi-disciplinary viewpoints and perspectives, and also providing a structure for solving design issues among stakeholders (ANUMBA et al., 2002). New opportunities have emerged due to the adoption of digital technologies, supporting the capture, verification, evaluation, control and testing of information, in addition to helping management, construction, use, operation and maintenance processes (CHEN; KAMARA, 2008; TEZEL; KOSKELA; TZORTZOPOULOS, 2016; KOSKELA; TEZEL; TZORTZOPOULOS, 2018; MURATA, 2018). Such practices are encouraging digitalisation or even automation, also enabling collaboration between stakeholders.

The connections between Lean practices, VM and ICT has been poorly explored in the literature (TEZEL et al., 2015; TEZEL; AZIZ, 2017). However, some studies have investigated the adoption of VM tools combined with ICT, in which digital technologies have provided opportunities for improving visual representation (KILLEN; KJAER, 2012), enabling an effective process of collecting, processing and displaying data (TEZEL; AZIZ, 2017), as well as data storage and traceability.

By contrast, visual communication can be regarded as an ancient mode of communication, which was recreated in parallel to the development of powerful ICT, aiming to support factories' communication. The technology emerged to support long-distance communications, potentially presenting an overload of channels, and the real problem was related to how to communicate effectively at close range (GREIF, 1991). Visual management was developed as a new way to communicate, work, produce and deliver more efficiently and quickly (GREIF, 1991). Thus, VM should deliver information in an easy and simple way, and digital technologies must support the process and not create difficulties in information transfer.

Recently, visual practices of communication have been pointed out in the literature as a support to efficient and fast decision-making activities (LINDLÖF, 2014), in addition to that the technologies present the potential to allow accessibility of information, availability of real-time data (DALLASEGA; RAUCH;

LINDER, 2018) and information feedback through an iterative and fast approach (TEZEL; AZIZ, 2017; VALENTE, 2017), considering the dynamic context. Availability of information can also increase operational capacity (DALLASEGA; RAUCH; LINDER, 2018), and improve the understanding of schedules (TEZEL; AZIZ, 2017). VM combined with ICT can facilitate the design process, through an ease creation of visual representation (DANSEREAU; SIMPSON, 2009 apud KILLEN, 2013).

The digital VM tools contributes to extend the application by improving some capabilities, e.g. (i) increase visibility with technologies; (ii) large data storage and analysis; (iii) problem-solving capability with the automation of information; (iv) geographical capability by high connectivity (MURATA, 2018). Murata (2018) explored the implementation of both analogue and digital approaches of VM strategies, as analogue tools will continue to exist in specific situations, such as communication and team-building processes. The cost and installation restrictions of digital technologies are considered as a barrier to the implementation of digital VM tools (TEZEL; AZIZ, 2017; MURATA, 2018), also encouraging the adoption of analogue tools in such situations.

The implementation of sophisticated VM tools can also generate negative impacts (EPPLER; MENGIS; BRESCIANI, 2008). Challenges related to the transfer of information among stakeholders involved in the processes may be related to the low transparency, inadequate information exchange processes and limited face-to-face communication (DALLASEGA; RAUCH; LINDER, 2018). Tezel and Aziz (2017) also pointed out some weaknesses of the technological scenario, such as poor integration and ineffective interoperability, and the lack of trained workforce. According to Murata (2018), new concepts are suggested to identify hidden problems in a digital visual system, as ‘waste of visualisation’ and ‘omission of visualisation’. The first concept is defined as the excess of information, which can cause misunderstandings and errors of interpretation and judgment. The second one refers to the difficulty of maintaining the details updated in a digital network, as well as the difficulty in selecting relevant information for each process.

Therefore, there is a limited understanding of the connection between visual management, design management, and digitalisation, as a result two main gaps in knowledge were addressed. Firstly, there is a need to understand how visual management can be better integrated into design management, exploring potential solutions across the hierarchical levels of design management. Secondly, there is a lack of understanding of how those VM tools can be combined with ICT to support design management.

1.4 RESEARCH QUESTIONS

Based on the research problem summarised in the previous section, the main question is:

How can visual management support design management in a digital environment?

The secondary question is:

- How can visual management be integrated into design management, across different hierarchical levels?

1.5 RESEARCH OBJECTIVES

The main objective of this research work is to **propose a set of VM requirements to support design management within digital contexts.**

The secondary objectives are:

- To devise a concept map connecting different VM constructs related to design management systems.
- To propose guidelines for the integration of Visual Management in design management within digital environment.

1.6 LIMITATIONS

Even recognising that VM can support the whole design and construction phases, the stages addressed in this investigation are limited to design development, i.e. conceptual design, preliminary design, and detail design. Moreover, the analysis of the connections between VM tools and managerial activities has not considered a wide range of tools that could support design management. The context analysed can also be considered a limitation of the research development, as the main empirical study was carried out in a single civil engineering design and consultancy company. There were also a limitation related to the evaluation of the solution, as this emerged at the end of the empirical study.

1.7 STRUCTURE OF THE DISSERTATION

This document is divided into seven main chapters. Chapter 1 is the introduction chapter, which contains the background, research problem, questions and objectives, and limitations. In Chapter 2, a literature review on design management is presents. Chapter 3 explores the literature on Visual Management. Chapter 4 presents the research method adopted in the research, describing the design science approach, the steps carried out in the empirical studies, and source of evidence. Chapter 5 describes the results of the exploratory and empirical studies. Chapter 6 contains the discussion about contributions of this investigation. Chapter 7 concludes the document with the final reflections, an appraisal of the research objectives and suggestions for future research.

2 DESIGN MANAGEMENT

This chapter is divided into four main sections. Section 2.1 discusses the nature of the design process, which is useful for understanding the complexity of design management. Section 2.2 discusses the inadequacy of traditional project management. Section 2.3 explores design planning and control, and discusses key concepts, mostly focused on the Last Planner System (LPS). Section 2.4 depicts the topic of collaboration in design, especially regarding interactions of different stakeholders in the design problems and their engagements.

2.1 NATURE OF THE DESIGN PROCESS

Design can be described as a process in which the problem and solution emerge at the same time: design problems and solutions are interdependent as design problems may suggest certain solutions, which can potentially create new problems (LAWSON, 1980). The design process is characterised as the analysis and evaluation of the proposed design against some criteria set by government regulations, industry standards and the clients (CROSS, 1995). It requires problem finding and solving, deduction, induction, analysis and synthesis (LAWSON, 1980). The inductive and deductive forms of reasoning are more commonly understood, however the abductive reasoning, related to synthesis, is central to design (CROSS, 1995). Abduction suggests the hypothesis that something may be and it is related to the kind of thinking used by researchers to explain the reasoning processes of designers (CROSS, 1995).

As the design problem cannot be fully understood independently of the solution, solution assumptions should be used as a means of helping to explore the problem definition (CROSS, 1995). According Cross (1995), a design problem consists of a goal to be achieved, and many constraints and criteria to be considered in order to achieve a successful solution. The problem context is often poorly defined and understood, but this can change as more information is made available and the project is more detailed (CROSS, 1995). In order to handle the uncertainty of ill-defined problems, designers need to define, redefine and modify the problem as required, in the light of solutions that emerge during the process (CROSS, 1995).

Traditional uncertainties are concerned with not only the lack of relevant information related expected events, but also the existence of technical and economic problems, whose solution are unknown, and the inability to trace precisely the consequences of the decisions and actions taken (ROZENFELD et al., 2006). Design peculiarities make rework less visible and quantifiable, if compared in the manufacturing activity, and defined (ROZENFELD et al., 2006). According to Rozenfeld et al. (2006), it is not less expensive in product development, as it appears hidden in the iterative nature of the design process.

Ballard e Koskela (1998) also argued that difficulties in managing the design are a consequence of the nature of the process, as decisions need to be made in an uncertain environment. Moreover, there are many factors that often push the design process away from the optimal design sequence, e.g. internal and external uncertainty, resulting in extended durations, low productivity and decreased value of the design solution (Koskela et al, 1997).

The most substantial difference between product development and production is related to the value aspect, which is much more relevant in design (KOSKELA, 2000). Some differences between these two processes are described in Figure 1, which allows a better understanding of nature of the product development. Product development process consists of a set of activities which aims to reach the design specifications of a product and its production process, based on market needs and technological possibilities and restrictions, and considering the company's competitive and product strategies (ROZENFELD et al., 2006). The design process is defined by Rozenfeld et al. (2006) as one of the stages of the product development process.

Figure 1 – Differences between production and product development

Production	**Product Development**
Produces physical goods	Produces information
Lower unpredictability and uncertainty	Higher unpredictability and uncertainty
Repetitive process	One-time process
Have standards for how long the work should take	The work expands to fill the available time
The work is either done or not done	It is difficult to determine when the work finishes
Likely to produce learning by repetition	Not likely to produce learning by repetition
Risk and variability must be avoided	Variability (necessary to create value) are desirable in some tasks

Source: Tzortzopoulos, Formoso and Betts (2001)

A formal representation of the process allows all participants to have an overview of it, including objectives, sources of information and design criteria (ROZENFELD et al., 2006). As described by Rozenfeld et al. (2006), the formalisation of project tasks requires a complete and unambiguous set of information, which will be used as a basis for the development of the later stages of the project process.

In this context, a clear and organised approach to design can help to coordinate teams, so that specialists' contributions and involvement are made at the right point in the process (CROSS, 1995). A systematic approach of dividing the overall problem into sub-problems is essential to allocate them to appropriate team members in the development of the project (CROSS, 1995). A large number of specialists collaborating in design also contribute to increase the complexity of design processes, as argued by Cross (1995).

2.1.1 Design as a process

Cross (1995) pointed out that the focus of design management is often the final document, e.g. drawings and product specifications, therefore the design process is neglected. Koskela (2000) identified the importance of integrating the concepts of transformation, flow and value generation with the TFV theory, proposing the application of a set of concepts and principles to the planning and control of the design process.

Lean design has been described as the application of lean production principles to design and engineering, emphasising the elimination of waste (activities that do not add value) in design processes (HAMZEH; BALLARD; TOMMELEIN, 2009; FOSSE; BALLARD, 2016). Freire and Alarcón (2002) also argued that this strategy considers the perspective of conversion, flow and value generation to describe the design processes (Figure 2).

Figure 2 – Transformation, flow and value generation perspectives.

	Transformation	Flow	Value Generation
Conceptualization of Engineering	As a transformation of requirements and other input information into product design	As a flow of information, composed of transformation, inspection, moving and waiting	As a process where value for the customer is created through fulfilment of his requirements
Main Principles	Hierarchical decomposition; control of decomposed activities	Elimination of waste (unnecessary activities); time reduction, rapid reduction of uncertainty	Elimination of value loss (gap between achieved value and best possible value), rigorous requirement analysis, systematized management of flow-down of requirements, optimization
Methods and Practices	Work breakdown structure, Critical Path Method, Organisational Responsibility Chart	Design Structure Matrix, team approach, tool integration, partnering	Quality Function Deployment, value engineering, Taguchi methods
Practical Contribution	Taking care of what has to be done	Taking care that what is unnecessary is done as little as possible	Taking care that customer requirements are met in the best possible manner

Source: Koskela (2000)

The transformation perspective is essential for identifying the design tasks, as well as effective for management. However, it has limitations in terms of identification of improvements, as value management is not considered (KOSKELA, 2000). The adoption of this view in isolation can be related to fragmentation problems in engineering projects, which consider more relevant the task itself than the interactions between different tasks (FREIRE; ALARCÓN, 2002).

According to Freire and Alarcón (2002), the flow view can potentially support the reduction of waste by eliminating design tasks related to inspection, rework, and information exchange from one stakeholder to the next one. It can also support the management of information transfer between designers, allowing the coordination of the flows interdependency and stakeholders integration (BALLARD; KOSKELA, 1998). The value generation perspective depends on the identification of client's requirements, considering the next customer in the process as well as the end user. Therefore, design improvement lies on the consideration of all requirements during the whole process, and the flow perspective considers the need of early and close involvement of the client as an approach to prevent the loss of value (BALLARD; KOSKELA, 1998; FREIRE; ALARCÓN, 2002).

Lean design integrates the flow and value perspectives, contrary to the traditional approach which considers only the conversion view (BALLARD; KOSKELA, 1998; FREIRE; ALARCÓN, 2002). However, Freire and Alarcón (2002) argues that the design processes include all the three visions related to different facets of design tasks and lean in design emerged as an approach to support the modelling toward the application of those perspectives in the design process. Such approach encourages the adoption of tools and techniques to integrate those design aspects and improve them (BALLARD; KOSKELA, 1998).

2.1.2 Design process issues

Some of the design process difficulties are related to slow approvals and inadequate time to complete design documents in a careful way, and, as a result, designers need to handle them without complete input information and, consequently, delay their tasks (KOSKELA; BALLARD; TANHUANPÄÄ, 1997). Most of the problems identified occur due to an incorrect translation of client requirements by designers or due to a late understanding of those needs, resulting in changes in late stages (ALARCÓN; MARDONES, 1998).

Information produced by design teams, as abstract information related to drawings, specifications and digital building models, defines how a facility will be constructed (TRIBELSKY; SACKS, 2011). The flow of information among them has an important role in supporting efficient work. Tribelsky and Sacks (2011) suggest that the rework can be associated with the information flows quality in an inverse way, as rework can reduced by making information available quickly. There is a discussion around the correlation of design outcomes and information flow issues, as the capability to find an effective solution early in design can reduce negative iterations in the processes (BALLARD; ZABELLE, 2000).

According to Tribelsky and Sacks (2011), ineffective flows of information can be related to different types of wastes, as rework associated with out of date information, initial set up time, extension of overall project durations due to negative iterations, and over-design without considering the additional or changed design requirements. The flow of information tends to be not well managed and understood, due to the lack of theory about it, as well as measures (TRIBELSKY; SACKS, 2011).

However, Freire and Alarcón (2002) also identified difficulties in implementing changes in the design processes, as people usually feel controlled when they need to specify the activities and how they managed their time. In fact, the identification of flows considering all the characteristics, e.g. variability, magnitude and type, is essential to understand them; and the barriers related to the human-nature tend to lose their relevance when the benefits from new strategies and methods start to emerge (FREIRE; ALARCÓN, 2002).

Projects also require an extensive diversity of professionals with a variety of skills, and sharing information is still a challenge considering that teams are rarely co-located (TRIBELSKY; SACKS, 2011), potentially resulting in a lack of design integration. The technical documents produced by the design team are essential for construction, when this process is poorly coordinated it can result in embedded incompatibility and inconsistencies, such as mismatch between associated segments and disciplines, inconsistency in design information across disciplines, and component malfunctions (MOKHTAR; BÉDARD; FAZIO, 1998). Mokhtar, Bédard and Fazia (1998) argued that it can result in change orders, contractual disagreements, budget overrun, time delays, compromise the quality, and client discontentment. Since 1998, there have been discussions about the lack of research to improve cross-disciplinary coordination, which can support the compatibility of the design information.

2.2 INADEQUACY OF TRADITIONAL PROJECT MANAGEMENT

Koskela and Howell (2002) stated the underlying theoretical basis of project management is obsolete, as it is based on an inadequate understanding of the nature of construction projects, as well as inadequate definitions of planning, execution and control. Those authors also pointed out that the existing theoretical foundation is not explicit (KOSKELA; HOWELL, 2002). Although management efforts and methods have progressed over time, different industries and sectors persist in tackling issues and achieving failed outcomes concerning the management (ATKINSON, 1999).

Koskela, Ballard and Tanhuanpää (1997) argued that the design management practice is often poor and the traditional prescription of project management approach is not enough for that context, as the identification of tasks and interrelationships as well as the preparation of the schedule are not sufficient for design processes; and the inherent variability at the task level has to be tackled by suitable production control methods (KOSKELA; BALLARD; TANHUANPÄÄ, 1997).

According to Koskela, Ballard and Tanhuanpää (1997), for achieving a truly outstanding design process, even more is required. Frequently, there is a need to find a trade-off regarding the schedule goals and the objective of considering the client requirements in an effective way (KOSKELA; BALLARD; TANHUANPÄÄ, 1997). The traditional management approach considers a causal connection with the management actions related to the organisation's outcomes (KOSKELA; HOWELL, 2002). Viana (2015) also argues that the traditional project management approach assumes that projects have a high level of causality and predictability.

Koskela and Howell (2002) divided the problems into three mains classes, which are: (i) project management does not perform in a satisfactory way and it tends to be counterproductive, affecting its performance, even more when considering big, complex and fast projects; (ii) the education and training has become more difficult, hampering effective professionalisation of project management due to the lack of theory; (iii) the lack of theory has also been hampered by the renewal of project management. The deficiencies and their detrimental effects can disseminate through the life cycle of a project (KOSKELA; HOWELL, 2002).

Koskela and Howell (2002) described the following problems: (i) client requirements are poorly investigated, so the process of requirement understanding and change leads to interference in the progress of the project; (ii) the actual progress starts to deviate from the plan, which is too complicated to be updated regularly; (iii) the work authorisation system changes to an informal management approach without an up-to-date plan; (iv) tasks are started without all inputs and requisites, leading potentially to task interruption, low efficiency or increased variability; (v) controlling is not based on the actual status, which can become counterproductive and ineffective. The project management is converted to a facade, behind which the work gets completed in an improvised way, which may result in reduced efficiency and decreased value generation to the client (KOSKELA; HOWELL, 2002)

The traditional management methods ignore some project attributes, for instance, the complexity and its consequences (WILLIAMS, 1999). There are different types of project complexity: (i) structural complexity, which is related to the number of stakeholders and systems involved, as well as the number of interdependences between them, and (ii) uncertainty, which is associated to the goals and means (WILLIAMS, 1999). Williams (1999) also suggest that complexity can be the result of: (i) organisational complexity, which is related to interdependences between organisational elements, e.g. the division of tasks and the number of hierarchical levels; and (ii) technological complexity, which is related to the number of different disciplines, tools, tasks or inputs. Williams (1999) described the increase of complexity directly connected with the increase of the elements, as well as the increase of simultaneity, which is a consequence of tight project deadlines.

Atkinson, Crawford and Ward (2006) also investigated issues related to the uncertainty, which can be divided into: (i) uncertainty in estimates, including the lack of a clear specification of requirements, lack of experience in the specific activity, and limited analysis of the process involving those activities; (ii) uncertainty associated with project parties, which may include the uncertainty about the level of performance that will be achieved, and different objectives and motivation from each party; (iii) uncertainty associated with stages in the project life cycle, defining uncertainty management issues for each stage.

Laufer et al. (2015) argue that a key challenge in project management is coping with frequent unexpected events. Such events can be described according to their level of predictability: (i) more intense than predicted; (ii) unpredicted; and (iii) unpredictable (PIPERCA; FLORICEL, 2012). These types of events can become problems that need to be addressed by the project manager (LAUFER et al., 2015). Traditional approaches of project management highlight long-term planning and focus on stability to manage risk; however, currently, managers leading complex projects often adopt both traditional and new methods which can support with greater flexibility and better results (LAUFER et al., 2015).

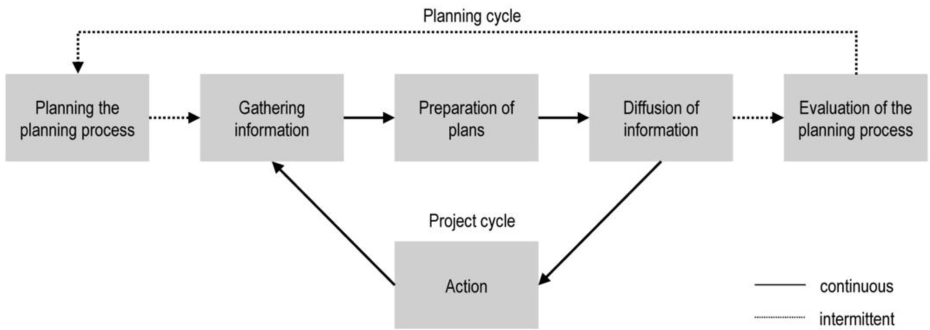
2.3 PLANNING AND CONTROL

2.3.1 Production Planning and Control

Planning is an early decision-making process in which the activities to be carried out are determined, as well as effective ways to carry it out (LAUFER; TUCKER, 1987). Therefore, the planning should define (i) the activities (what should be done), (ii) the methods (how to do), (ii) the resources (who will perform), the sequence (when it should be performed) (LAUFER; TUCKER, 1987). Koskela, Ballard and Tanhuanpää (1997) pointed out that design and construction processes demand planning at different hierarchical levels due to the high level of uncertainty. Planning is defined as a multi-level and hierarchical process, which can be divided into specific stages with different components of planning and a gradual increase in the level of management and detail (LAUFER; TUCKER, 1987): (i) the first stage (strategic), in which the scope of the project and its goals are defined; (ii) middle management (tactical), in which the means, i.e. resources, are identified; and (iii) lower management (operational), which is related to selecting and devising the solutions and actions to be performed. Therefore, planning at a strategic organisation level tends to focus on overall goals and constraints, which drive lower planning levels, specifying the means to achieve that (KOSKELA; BALLARD; TANHUANPÄÄ, 1997).

According to Laufer and Tucker (1987), the planning process must include five main stages, (Figure X), which are: (i) planning the planning process, defining e.g. the planning levels, the update frequency, level of detail, key stakeholders involved and their responsibilities (LAUFER; TUCKER, 1987; FORMOSO et al., 2001); (ii) gathering information; (iii) preparation of plans, considering the processes resources, deadlines and costs; (iv) diffusion of information to the right stakeholders; identifying the nature of information, frequency, format and feedback cycle; and (v) evaluation of the planning process, supporting the improvement of planning process for future projects. Laufer and Tucker (1987) also suggest the planning cycle, defined as an intermittent cycle, and the project cycle, characterised as a continuous cycle.

Figure 3 – The planning process



Source: Laufer and Tucker (1987)

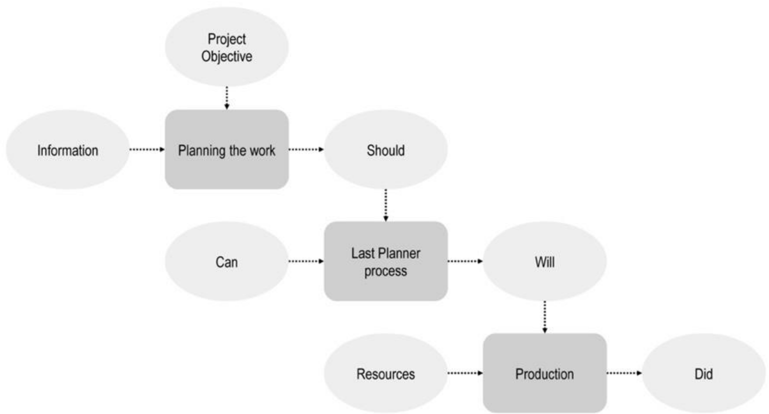
These are the main shortcomings in planning and control in construction: (i) focus on the scheduling, while the planning methods are neglected (focus); (ii) inadequate control, which overshadows action planning (role); and (iii) emphasis on emergency decision making, ignoring the preceding steps required for decision making (process) (LAUFER; TUCKER, 1987). The lack of planning, in turn, exposes the production process to uncertainty and variability, resulting in interruptions in the execution of activities, changes in pace, among other negative impacts (FORMOSO et al., 2001). Laufer and Tucker (1987) pointed out that the problems arise mainly due to the inadequate qualification, guidance and motivation of the parties involved in the process.

2.3.2 Last Planner System (LPS)

The Last Planner system (LPS) is a production planning and control model for the construction sector, which aims to increase workflow reliability and shields the production system from uncertainty (BALLARD, 2000). The Last Planner system was created with the intention of providing a missing aspect from the traditional project management and it was also assumed that the delivery of this missing component would avoid the poor project performance, which had become a characteristic of the traditional approach (BALLARD; HOWELL, 2003).

LPS can be regarded as a strategy to transform what should be done (SHOULD), into what could be done (CAN), thus, creating an inventory of ready work and removing the constraints, which can support weekly work plans (BALLARD, 2000; BALLARD; TOMMELEIN, 2016). It also includes assignments on Weekly Work Plans, which is characterised as a commitment to what they actually WILL do (Figure 4).

Figure 4 –Last Planner System



Source: Ballard (2000)

A taxonomy for task breakdowns between different levels of detail characterises the LPS; the methods can be described as: (i) for specifying Should, i.e. pull planning; (ii) for lookahead planning/make ready; (iii) for increasing workflow reliability; (iv) for learning from plan failures, (v) metrics (BALLARD; HOWELL, 2003; BALLARD; TOMMELEIN, 2016). LPS includes a set of tools that allows the implementation of the following procedures: (a) production unit control, through the progressive improvement of work, encouraging continuous learning and corrective actions; (b) workflow control, causing information or materials work to flow across production units in the best possible sequence and rate (BALLARD, 2000). Farook et al. (2009) described the design planning process according to four stages: (i) master schedule, (ii) phase schedule, in which there is an alignment of milestones among stakeholders, (iii) lookahead plan, and (iv) weekly work plan.

2.3.3 Design Planning and Control

Several studies on the implementation of LPS in the design process were explored in the literature (KOSKELA; BALLARD; TANHUANPÄÄ, 1997; MILES, 1998; TZORTZOPOULOS; FORMOSO; BETTS, 2001; BALLARD, 2002; DEN OTTER; EMMITT, 2008; HAMZEH; BALLARD; TOMMELEIN, 2009; WESZ; FORMOSO; TZORTZOPOULOS, 2018; KEROSUO et al., 2019). One of the first investigations on this topic refers to the implementation of this system in a construction design project in Finland (KOSKELA; BALLARD; TANHUANPÄÄ, 1997). Koskela, Ballard and Tanhuanpää (1997) described two main benefits related to the use of LPS in design management. The design process is made more transparent through PPC metrics and schedule, enabling the early analysis of design schedule alterations and visibility of erratic decisions through the metrics (KOSKELA; BALLARD; TANHUANPÄÄ, 1997). The second benefit identified is related to the design performance metrics, which supports the comparative analysis of the targets and monitors the design progress. The deficiency of metrics can hamper the improvement of design management (KOSKELA; BALLARD; TANHUANPÄÄ, 1997).

The design process can be more disciplined when compared to the implementation of traditional design management approaches, even considering that only part of the Last Planner elements can be adopted (KOSKELA; BALLARD; TANHUANPÄÄ, 1997). Hamzeh, Ballard and Tommelein (2009) highlight the importance of standardising the planning and control process, making it possible to measure and improve the process, and of training of LPS, which contributed to fast implementation of the planning process. The same authors also point out the support of the high and middle management and the use of the short-term planning tool i.e. a common agenda, as essential for the success of the LPS deployment. Meetings are described as essential to improve team communication and encourage socio-emotional interaction, being especially important for adjusting and synchronizing activities in simultaneous project teams (DEN OTTER; EMMITT, 2008). The leadership role is emphasised in Den Otter e Emmitt (2008) discussions, as the benefits and the level of collaboration of the meetings are related to the ability of the chair to conduct the meeting.

The LPS implementation in design can increase the number of completed tasks, as observed by Kerosuo et al. (2019), changing the reactive orientation from traditional design meetings to proactive orientation aspects related to LPS meetings, with team members being accurate and punctual in setting future tasks. Kerosuo et al. (2019) also suggest that new strategies of conversation emerged in the LPS meetings, where the main designer presented an initiative to discuss the reorganisation of design activities when cross-discipline knowledge was needed. Kerosuo et al. (2019) suggested that the design management still presents grey areas in respect of quality requirements and achieving goals. It is beneficial to reach the main targets by discussing through collaborative practices, however some old practices are still persistent and, therefore, changes for new ones can take time.

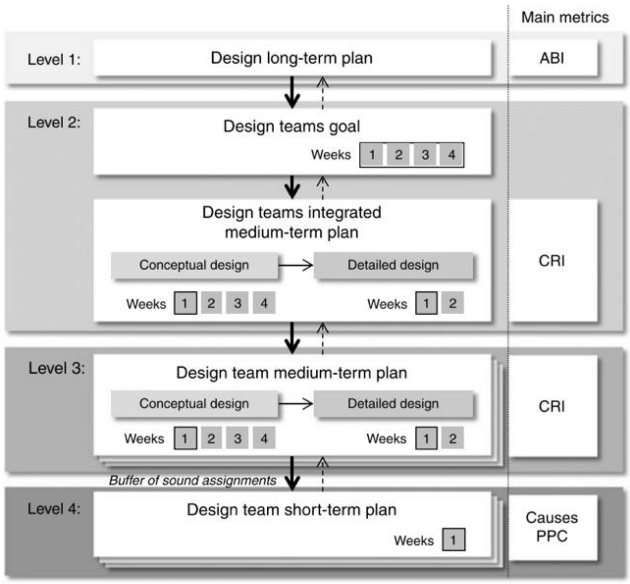
Neglecting the nature of design activities is a common mistake when devising planning and control systems, especially regarding the consideration of project uncertainty and variability (WESZ; FORMOSO; TZORTZOPOULOS, 2018). The causes of failure to complete plans are related to the variability of the overall design process, e.g. lack of input and definition of the project, and to the internal planning and management of each project team, e.g. lack of time due to other activities and underestimation of tasks time (KOSKELA; BALLARD; TANHUANPÄÄ, 1997) and effort required to perform the assignment (MILES, 1998). In addition, Miles (1998) identified the delay in the input of information by the client as one of the difficulties encountered in the LPS implementation, resulting in impacts on productivity and project delays. Koskela, Ballard and Tanhuanpää (1997) argued the difficulties in defining the root causes of non-completion of activities, and, consequently, in defining an action plan to avoid the problems detected. Tzortzopoulos, Formoso e Betts (2001) identified difficulties in determining the project activities in the initial phases, due to the degree of uncertainties, considering that the definition of activities depends mostly on the design decisions. Difficulties related to the identification of restrictions were also identified, resulting in partial implementation of medium-term planning (TZORTZOPOULOS; FORMOSO; BETTS, 2001).

Wesz, Formoso, Tzortzopoulos (2018) emphasised the limitation in using of visual management to make planning information available. Such practice can not only collaborate for the standardisation, effective and systematic use of the planning and control process, but also increase the transparency and availability of information (WESZ; FORMOSO; TZORTZOPOULOS, 2018). Wesz, Formoso, Tzortzopoulos (2018) also pointed out limitations in evaluating the implementation of project planning and control practices.

Wesz, Formoso, Tzortzopoulos (2018) proposed a design planning and control model, which is divided into four hierarchical levels (Figure 5), and includes some key foundations of the LPS. Level 1 is the long-term planning, that considers all projects based on deadlines defined in contracts and on the integrated medium-term design plan, in which monthly goals are defined (WESZ; FORMOSO; TZORTZOPOULOS, 2018). Adherence to batch index (ABI) is the main metric implemented to control monthly productivity adherence to long-term plan (WESZ; FORMOSO; TZORTZOPOULOS, 2018).

At Level 2, an integrated medium-term design planning meeting is conduced weekly, in which visual tools support joint analysis of key constraints for design development (WESZ; FORMOSO; TZORTZOPOULOS, 2018). The integrated look-ahead plans are updated weekly, considering four weeks ahead for conceptual design and two weeks ahead for detail design. Constraint removal index (CRI) is the main metric used at that level (WESZ; FORMOSO; TZORTZOPOULOS, 2018). At Level 3 and 4, a weekly meeting is held individually with each design team to produce a medium-term plan (Level 3) and a short-term plan (Level 4) (WESZ; FORMOSO; TZORTZOPOULOS, 2018). Analysis of constraints is carried out, besides that a backlog of assignments to the short-term plan is prepared at the operational level. CRI is the metric used at medium-term plan, and causes for the non-completion of work and PPC are the indicators implemented at short-term plan (WESZ; FORMOSO; TZORTZOPOULOS, 2018).

Figure 5 – Proposed design planning and control model



Source: Wesz, Formoso, Tzortzopoulos (2018).

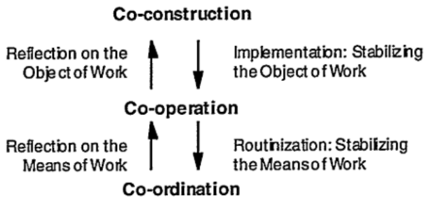
2.4 COLLABORATION IN DESIGN

Design is an activity in which a team should work collaboratively towards a final solution, and it emerges as a result of the interaction between design team members, the artefact, other professionals and the environment (SAAD; MAHER, 1996). Collaborative processes demand a shared understanding by the stakeholders involved, rather than simply sharing knowledge (KLEINSMANN; VALKENBURG, 2008), as it is a process related to the creation, exploration, information sharing, and integration of knowledge to develop common processes, products, and goals (PIKAS et al., 2016). The management of knowledge boundaries is also important to achieve those aspects, involving collective learning through negotiating, debating, and combining of different perspectives and interests (PIKAS et al., 2016).

Wood and Gray (1991) describe collaboration as an interactive process which should engage autonomous stakeholders in the same problem, who must consider regulations, standards and shared structures to support actions and decisions. Collaboration is defined as an interorganisational relationship with a mutual benefit, based on transparency and trust; aiming to maximize the value for the customer by solving problems jointly through interactive processes, and by sharing responsibilities, rewards and risk between key participants (SCHÖTTLE; HAGHSHENO; GEHBAUER, 2014). Establishing common values and objectives is essential to drive collaboration and reduce disagreement in projects, but sharing values is still considered a challenge by organisations, individuals and temporary project groups (EMMITT; SANDER; CHRITOFFERSEN, 2006). The communication, cooperation, competences and values of stakeholders are essential aspects in supporting the achievement of integration, as suggested by Emmit, Sander and Chritoffersen (2006).

Bardram (1998) presents a different perspective on collaboration, stating that any human activity involves dynamic transformation between hierarchical levels of collaborative activities, which are: coordination, cooperation and co-construction (Figure 6). The aim of coordination is to make different stakeholders gathered together to act upon a common objective, although the individual activities are only externally related to each other (BARDRAM, 1998). Cooperation means that various actors are focused on a common object, sharing the objective of the collaborative activity (BARDRAM, 1998). In co-construction, collaborative work is described by interactions in which the stakeholders focus on re-conceptualising their organisation and relation with shared objects (BARDRAM, 1998). According to Bardram (1998), the collaborative activity has to be jointly constructed at this level.

Figure 6 – The dynamics of collaborative work



Source: Berdram (1998)

Collaborative work between different specialists and professionals, such as designers and contractors, is increasingly necessary in construction projects. It can involve participants with different skills and expertise, which is also described as a complex group activity (EDMONDS et al., 1994). Design and construction information is highly interdependent (JIANG; LEICHT, 2016), and the understanding, definition and capture of such interdependencies are essential to support collaborative and integrated work. The design process is characterised by the iteration between disciplines, which may be beneficial, for value generation, and should only be controlled due to implication in time and cost (KNOTTEN et al., 2015).

In design, there is much interdependence between stakeholders, which places pressure on the capability to communicate, transfer and share knowledge and information between them (EMMITT; SANDER; CHRITOFFERSEN, 2006). Effective communication is also related to the establishment of interpersonal, intra-organisational and inter-organisational communication, providing learning to improve value generation, as decisions made by groups are more accurate and coherent considering there is a wider range of information and knowledge accessible to stakeholders (EMMITT; SANDER; CHRITOFFERSEN, 2006). Emmitt, Sander and Chritoffersen (2006) collaborative processes demand more meetings, as they encourage dialogues, and support the understanding of existing cultural values.

Kleinsmann and Valkenburh (2008) explored the complexity of collaborative design, arguing the fact that barriers and enablers that impact a shared understanding affect communication, project management and project organisation. The same authors have identified enablers and benefits of shared understanding in design projects for three organisational levels: the actor, project, and company. The results of that study have indicated that the enablers and barriers on the different organisational levels were related to each other, e.g. barriers and enablers related to the interface between the design team and software development. There is a lack of shared understanding between participants at the actor level as they can use different representations, affecting the communication and cooperation (KLEINSMANN;

VALKENBURG, 2008). At the project level, Kleinsmann and Valkenburh (2008) argued that there are problems related to the iterative cycles in development, planning, and monitoring processes. At the company level, difficulties are related to the strategy definition for the adoption of technologies, as a result of the lack of knowledge about the new emerging technology (KLEINSMANN; VALKENBURG, 2008). Taking that into consideration, the same authors suggested that new interfaces need to be clearly defined and actors should be trained about the new process.

Different communication and collaboration approaches also support project managers to cope with unexpected events in project management. The development of collaboration is one of the roles developed by managers, which supports to select the right people and develop mutual interdependence and trust (LAUFER et al., 2015). Maintaining forward momentum is also considered a project manager role, which can resolve problems by hands-on engagement, updating and connecting through frequent face-to-face communication, moving about (walk the floor) frequently (LAUFER et al., 2015).

Collaboration is classified by Ugwu et al (1999) in four different types, considering collaboration depends on the nature of separation (i.e. same place or different place) and timing of communication among participants (i.e. same time or different times) in a project (Figure 7): (i) face-to-face collaboration, described as a face-to-face meeting attended by stakeholders in a common space; (ii) asynchronous collaboration, in which a medium for communication, such as bulletin or notice, is used to enable collaboration; (iii) synchronous distributed collaboration, involving real-time communication with the support of the information and communication technologies, e.g. virtual co-location of team members; and (iv) asynchronous distributed collaboration, in which communication is carried out by using post, mail transmissions, among others.

Figure 7 – Collaboration models

Collaboration models	**Same time**	**Different times**
Same Place	Face-to-face collaboration (FFC)	Asynchronous Collaboration (AC)
Different Places	Synchronous Distributed Collaboration (SDC)	Asynchronous Distributed Collaboration (ADC)

Source: Ugwu et al (1999) and Anumba et al. (2002)

Den Otter and Prins (2002) also explored the human communication side, defining three main categories of communication: (i) *'face to face meetings'*, described as verbal communication associated with non-verbal interactions; and *'on distance' communication*, defined as short verbal messages or non-verbal documents; (ii*) formal and informal communication*, in which formal interactions are based on structured communication, agreements and rules for information transfer, whereas the informal intersections are characterised as unstructured and interactive exchanges without rules and hierarchies; (iii) types of information exchange, described as *not document based graphical information* (non-verbal and verbal communication), *document-based static* (graphical information, as drawings and sketches), *non-graphical information* (text, numbers, matrices), and *document-based dynamic* (video and audio).

2.4.1 Design coordination

Schöttle, Haghsheno e Gehbauer (2014) describes design coordination as the organisation and planning of different activities, involving cooperation and collaboration between two or more parties. Cooperation and collaboration is concerned with how stakeholders interact, as they are unable to reach project goals without interorganisational relationships (SCHÖTTLE; HAGHSHENO; GEHBAUER, 2014).

Isatto and Formoso (2006) classified coordination into three dimensions in order to describe the coordination among the supply chain members, which are: (i) process dimension, described as the flow of the objects of the work (e.g. products or share of information flow); (ii) social dimension, which aims to coordinate actions of different companies and people; and (iii) economic dimension, aiming to provide economic stimulus for the companies to take part in the interactions processes required to deliver value to the client. The dimensions of coordination defined by Isatto and Formoso (2006) might be used to organise work among different organisations, to achieve and maintain cooperation and to coordinate processes implementation, considering a certain degree of autonomy.

Those dimensions consider distinct economic agents who are connected by the processes or flows that occur between them, which can be described as: flow of products, flow of information, flow of money and flow of value (ISATTO; FORMOSO, 2006). The flow of value is usually considered the most important one, incorporating all the other processes (ISATTO; FORMOSO, 2006).

Those three dimensions described by Isatto and Formoso have a complementary nature and must be regarded simultaneously, otherwise there is a risk of supply chain failure as a result of the (i) lack of cooperation (affecting the economic dimension), (ii) poor coordination (affecting the social dimension) between the members, (iii) deficit of competitiveness in the supply chain (affecting the process dimension) (ISATTO; FORMOSO, 2006).

2.4.2 Collaboration in digital design

Collaborative working has traditionally been based on physical meetings between representatives of the principal design disciplines, and the ICT that are currently available have been adopted to support those activities (ANUMBA et al., 2002). Digital information exchange, storage and publication, such as exposing useful information using public media, are considered important in digital design (DEN OTTER; PRINS, 2002). Considering the nature of digital information, design teams must develop more proactive and interactive skills, collaborating with the process, as the information is more explicit in digital approaches (DEN OTTER; PRINS, 2002). Den Otter and Prins (2002) highlighted the importance of verbal and informal communication at the very early design phases; however, the effective documentation of these decisions considering accessibility and transparency aspects of stored information is essential to improve the process. Most of software systems eventually fail without the cognitive work that people engage in with each other (WOODS; ALLSPAW, 2019).

The effective information exchange through collaborative approaches can support issues related to multidisciplinary projects in context of concurrent design and engineering projects, which are described as (i) high level of information sharing, (ii) a degree of formal communication, (iii) plenty of standards for information storage and transfer, (iv) a diversity of information tools and systems adopted by design partners (DEN OTTER; PRINS, 2002). Considering that, digital information is becoming accessible and available to all stakeholders, they should be encouraged to develop more digital skills. Design teams tend to become more vulnerable to digital tools adopted in collaborative processes, as they become dependent of the connectivity and on the tools used (DEN OTTER; PRINS, 2002).

Despite the large number of stakeholders involved in a project, the design of the ICT systems rarely gives explicit attention to the coordination requirements and aspects (MAGUIRE, 2019). The information and communication technologies usually consider the follow aspects: (i) concentrating coordination response with a leader; (ii) implementing an excessively prescriptive process management approach, that fails to consider the hidden cognitive work of coordination; or (iii) depending on tools that fail to completely support the nonlinear and dynamic perspective in which incident coordination response happens (MAGUIRE, 2019). Thus, the approaches described by Maguire (2019) do not necessarily support the cognitive work of coordination as intended. Some difficulties were highlighted by Anumba et al (2002), such as the use of diverse software tools and the lack of effective collaboration tools that are necessary to reduce the time and distance constraints, increasingly required by distributed design teams work.

Previous research has pointed out that poor coordination design induces to cognitive costs for specialists, particularly, an additional mental effort and capacity needed to take part in joint activities (MAGUIRE, 2019); and digital systems, adopted across geographically distributed groups, can exacerbate those cognitive costs (MAGUIRE, 2019). Maguire (2019) argues that there are plenty coordination costs in human-machine interactions that are intensified by tool design or go undetected. A key aspect of the dynamics of teamwork when considering human-human and human-machine arrangements is related to the degree in which participants consider the workload, goals, and needs of others and their actions in the collaborative activity (MAGUIRE, 2019).

3 VISUAL MANAGEMENT

This chapter is divided into seven sections. Section 3.1 provides definition of visual management. Section 3.2 describes the principles related to process transparency, which are important for the development of this research study. Section 3.3 explores visual languages and visualisation. Section 3.4 investigates visual management taxonomies. Section 3.5 explores the implementation of VM in planning and control. Section 3.6 discusses information management and digitalisation. Section 3.7 summarises a set of core constructs for this research study.

3.1 DEFINITION OF VISUAL MANAGEMENT

Visual Management (VM) can be defined as a set of practices that support visual communication through the adoption of different visual tools (TEZEL; KOSKELA; TZORTZOPOULOS, 2016). According to Igarashi (1991), VM allows an easy identification of waste, problems and non-conformances. A visual tool is a mechanism that influences, directs, limits or controls behaviour, making information essential to a specific task available immediately, without the need for explanation (GALSWORTH, 2017). A visual system is defined by Galsworth (1997) as a set of visual tools that are designed to facilitate the sharing of information between different stakeholders, providing information fundamental to specific tasks or processes at a glance. VM represents a paradigm to manage and control information (TEZEL; KOSKELA; TZORTZOPOULOS, 2016).

Beynon-Davies and Lederman (2017) state that visual management is a way to make actions visible, improving workflow. Regardless the context, VM is based on artefacts that are used by different people to obtain the necessary information for a task or action, being important the position that they take in the workplace (BEYNON-DAVIES; LEDERMAN, 2017). The terms collaborative visualisation and shared visual representations are widely adopted to highlight collaborative dimensions of visual management practices (VALENTE; PIVATTO; FORMOSO, 2016).

This research investigation considers the following definitions: (i) VM tool refers to the perceptible visible portion of the artefact, characterised by Valente, Brandalise and Formoso (2019) as visual tool attributes; (ii) VM practice refers to the visual work and non-visual work, considering the invisible effort highlighted by Nicolini (2007); (iii) VM system, which consists of a group of visual tools that work together to provide a visual work environment (GALSWORTH, 2017), and can also be described as sets of visual practices, which should be integrated within managerial processes (VALENTE; BRANDALISE; FORMOSO, 2019).

VM is used for different purposes according to the context in which it is introduced. As described by Tezel, Koskela and Tzorzopoulos (2016), the objective is to increase information availability, provide assistance for sensory work and remove blockages in the transfer of information. It is a strategy that presents the potential to facilitate transparency across planning execution and control interfaces and also to facilitate the information flow (BRADY et al., 2018). In addition to increasing transparency, other purposes for VM have been pointed out in the literature, such as: enabling collaboration among stakeholders (EWENSTEIN; WHYTE, 2009), encouraging a sense of shared ownership, and assisting on-the-job training (TEZEL; KOSKELA; TZORTZOPOULOS, 2016). Visual management is a means to improve transparency, communication or collaboration, and not an end itself (VALENTE; BRANDALISE; FORMOSO, 2019).

Valente, Brandalise and Formoso (2019) argue that the main objective of the practices adopted in the construction is related to the standardisation of its processes, also supporting the reduction of variability. In other sectors, those tools are used to stimulate creativity and collaboration among users (VALENTE; BRANDALISE; FORMOSO, 2019). VM has the role of providing information clearly, especially in complex environments, it can be used to assist in the coordination of processes between interdependent parties (VIANA et al., 2014).

The use of visual tools can also contribute to cognitive, social and emotional benefits (BRESCIANI; EPPLER, 2008). VM can also improve communication, increase information processing capability of teams and contribute to handling uncertainty and ambiguity in design (LINDLÖF, 2014). Visual representations can provide efficient strategy for communicating and displaying information, as a way to assist in strategic decision making (KILLEN; KJAER, 2012).

VM supports information management in a wide range of functions for an organisation, such as filtering, monitoring, simplifying and effectively presenting relevant information (TEZEL; KOSKELA; TZORTZOPOULOS, 2009). VM considers some aspects of information, such as relevance, accuracy, immediacy, and location as close as possible to relevant places or integration with the workplace or process (TEZEL; KOSKELA; TZORTZOPOULOS, 2009).

VM can also support continuous workflow, allowing problems to be detected and corrected before they affect and interrupt the system (BRADY et al., 2018). Viana et al. (2014) and Murata (2018) argue that

VM makes information explicit and available, so previously hidden data make employees question old practices and the top-down approach (VIANA et al., 2014). It also supports people to understand and quickly solve potential abnormal and hidden conditions in the system, reinforcing the value chain related to the lean management (MURATA, 2018). Information can be visible at the right time, to the right user, in the right place, as described by Ortiz and Park (2011) for the manufacturing context, through visual and easily comprehensible tools.

Tezel, Koskela and Tzortzopoulos (2016) argued that VM has evolved through a set of unconnected and distributed efforts, mainly by practitioners. VM is mostly conducted to practitioners with a broad focus on a superficial “how”, also described as practical approach, e.g. effort focused on helping to solve specific information need problems, instead of an detailed “what”, considered more conceptual (TEZEL; KOSKELA; TZORTZOPOULOS, 2016). Thus, understanding the key functions that VM can perform is substantial to encourage the dissemination of those tools into different sectors and work setting (TEZEL; KOSKELA; TZORTZOPOULOS, 2016). Tezel, Koskela and Tzortzopoulos (2016) also argued that VM presents the potential to be implemented wherever there is a communication need or human and process elements interactions. According to Valente, Brandalise and Formoso (2019), it is important to consider mental models, the creative process and visual identity, associated with social and cultural issues.

According to Beynon-Davies and Lederman (2017), the theory of affordances explains how visual management works The theory of affordances attempts to explain how actors use their sense and, mainly, vision, to perceive the structures in the environment as an indication of action (BEYNON-DAVIES; LEDERMAN, 2017), explaining where affordances are in visual tools. The affordance concept seems especially appropriate to help describe actions in relation to material or physical artefacts used for informative reasons (BEYNON-DAVIES; LEDERMAN, 2017). Beynon-Davies and Lederman (2017) argue the need of communicating the patterns and opportunities of action expected by certain actors in relation to those artefacts.

Based on a literature review, Valente, Brandalise and Formoso (2019) proposed recommendations for the adoption of visual management, described as: (i) combining mental models of designers and users, so that the visual tools really become intuitive and easy for users to understand and use considering previous individual assumptions, beliefs, experiences that influence behaviour; (ii) contributing to cultural change, the implementation of a visual tool can change the way employees feel about their work, providing increased morale and motivation; and (iii) mitigating problems related to the complexity of the system, a VM system can contribute to dealing with part of this complexity, sharing the right information at the right time and removing information barriers in the work environment. The same authors also proposed some additional guidelines, based on empirical studies: (i) ensure rapid feedback, so that decisions can be made on time, making it more important to the process and to people, in some cases, the idea of autonomation can be used to develop visual tools that produce immediate feedback with the use of appropriate technology; (ii) support communication rituals or daily and collaborative meetings, as visual tools associated with control and learning events and also with moments of reflection can facilitate the control of information and the improvement of processes based on data analysis; and (iii) encourage joint information processing, as the VM system can support collaborative activities in organisations, and visual tools can be used as catalysts for collaborative processes to facilitate a variety of tasks, achieve consensus, etc. (VALENTE; BRANDALISE; FORMOSO, 2019).

3.2 THE PRINCIPLE OF REDUCING PROCESS TRANSPARENCY

The principle of reducing process transparency consists of making the production process comprehensible and observable to all stakeholders by using public display of information, measurements, and physical means (KOSKELA, 2000). It is also defined as the ability of a process (or its parts) to communicate with all participants (FORMOSO; SANTOS; POWELL, 2002). The transparency is one important principle of operations management, however, due to construction peculiarities, it is challenging to implement this principle in practice (KOSKELA, 2000).

Transparency can be adopted as a principle to increase the visibility of errors, increase the motivation of workers regarding the improvements, and reduce the propensity of errors (KOSKELA, 1992). Process transparency can also encourage autonomy by enabling employees to get involved in process management and support early identification of mistakes and deviations (MOSER; SANTOS, 2002; KLOTZ et al., 2008). The transparency, trust, open access to information, experience, and knowledge sharing of collaborative environments support the achievement of lean principles, e.g. value maximization for the customer and waste reduction, as discussed by Schöttle, Haghsheno e Gehbauer (2014).

Greif (1991) states that process transparency means that information is no longer transmitted in linear flows, but it is available in the information field, in which information is demanded by anyone at any time. As stated by Ohno (1988), there is a need for information to be ‘pulled’ as required during the process. The information available in advance or the excess of information may generate confusion in the process sequence, cause difficulties in producing an item when needed, or it can encourage the excess of production, which may be defective (OHNO, 1988).

The information transparency is defined by Klotz (2008) as the transparency related to (i) organisational of the process, (ii) sequence of the process, and (iii) product information, see examples on Figure 8. Transparency can also contribute to have coherent and simplified decision making, encourage informal communication across hierarchical levels, support decentralisation policies, enable an effective distribution of responsibilities, increase employee morale, and encourage the process simplification (MOSER; SANTOS, 2002).

Figure 8 – Types and examples of information transparency.

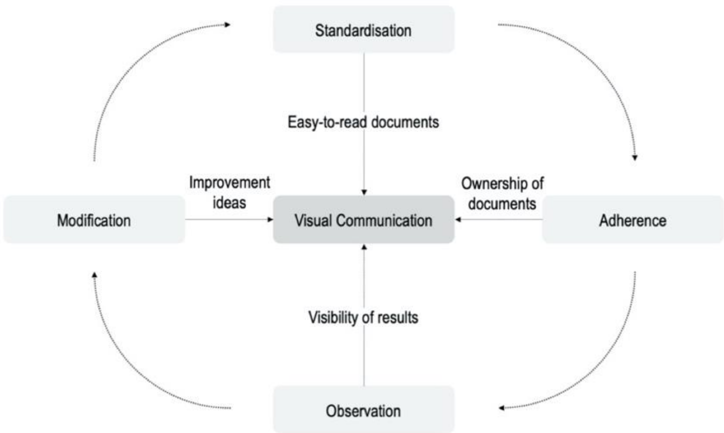
Process (organisation)	Process (sequence)	Product
Example: Contractual relationship, organizational boards	Example: Schedule, process maps	Example: Virtual models, 3D models, drawings

Source: adapted from Klotz (2008).

Transparency can also be described as process visibility, defined as: (i) recognition of status, issues, responsibilities and interdependencies; (ii) facilitation of understanding, feedback, communication and improvements; and (iii) training to decision making considering total understanding of the process (KLOTZ, 2008). The recognition aspect is characterised as: (a) recognition of status which relates to the understanding of the position of the process; (b) recognition of problems that supports the identification of concerns in the process; (c) the recognition of stakeholders' responsibilities which facilitates an understanding of their role in the process; (d) recognition of stakeholders interdependencies which enables an understanding of how they are impacted by others and will impact within the process. The facilitation aspect is described as: (a) facilitation of system performance understanding in which stakeholders can evaluate process efficiency; (b) facilitation of feedback on performed activities can determine whether their actions are accurate; (c) facilitation of stakeholders' communication are tools which allow successful communication; (d) facilitation of improvements can identify means to create value and eliminate waste, supporting continuous improvement. The process visibility also enables decision making, in which the essential tools are given to participants so that they can feel comfortable making decisions, considering a total process understanding.

The standards of visual communication are needed for process improvement and visual organisation, simplifying the whole process (GREIF, 1991), also improving the transparency. According to Greif (1991) visual communication is influenced by process standardisation, adherence, observation, and modification (Figure 9): (i) standardisation contributes to make documents clear and understandable; (ii) sense of ownership of the documents increases adherence; (iii) the visibility of the results supports a greater observation of the process, encouraging constantly questioning of standards, since they are easily accessible; and (iv) modification is necessary to support improvement of ideas and suggestions. Greif (1991) also argued that everyone should be involved with the creation of standard documents, and that a good standard always evolves, inspiring improvements.

Figure 9 – Visual communication.



Source: Adapted from Greif (1991)

Therefore, different ways of communication have explored and transformed the relationship between humans and knowledge, and this transformation can be summarised in three key points (i) workers becoming directly involved in knowledge management, developing their own methods; (ii) visual documentation creating a field of knowledge which allows information sharing and adaptation of rules and methods; and finally (iii) visual communication enhancing employees' autonomy and mobility, as well as improving employees' participation through the visibility of standards (GREIF, 1991).

3.2.1 Approaches to improve process transparency

Koskela (2000) proposed some practical approaches that can be used to increase process transparency, such as: eliminating clutter by cleaning the space (5S), making the process directly observable within the appropriate signage and layout, standardising, using measurements to transform invisible attributes into attributes visible in the process, incorporating process information into work areas and information systems, allowing patterns and deviations to be recognised immediately through the adoption of visual controls, and reducing the interdependence of production units. Formoso, Dos Santos e Powell (2002) explored definitions adopted for each practical approach, related to evidences obtained in case studies.

A process can be made directly observable by proper planning of the workstation flow, removing visual barriers, improving illumination of the working environment, or through an appropriate layout design (FORMOSO; SANTOS; POWELL, 2002). This approach facilitates the observation by each team of what is happening in other workplaces, including delays and technical problems (FORMOSO; SANTOS; POWELL, 2002). Another relevant approach is related to the use of visual tools to enable immediate recognition of process status, which can provide easy access to the required information supporting the identification of problems visually, particularly when standards are not being followed (FORMOSO; SANTOS; POWELL, 2002).

Incorporating valuable information into the process can also support the increase of transparency; and it is mostly related to guidelines on how to perform the work (FORMOSO; SANTOS; POWELL, 2002). The information content can vary from specific information of the processes or products to general information related to the company (FORMOSO; SANTOS; POWELL, 2002). Rendering invisible attributes visible through measurements can also contribute to a transparent environment, as some of the processes or product attributes that usually are not visible are externalised (FORMOSO; SANTOS; POWELL, 2002). As described by Formoso, Dos Santos and Powell (2002), the implementation of performance measurement depends on some factors, such as: (i) continuous improvement activities systematically carried out by the workforce and (ii) efforts to integrate and standardise data collection and processing processes, aiming the implementation of performance indicators that can be used in different sectors of the company.

3.2.2 Issues related to the lack of process transparency

Brady et al. (2018) identified some issues, based on literature review, in which the lack of transparency leads to communication and coordination failures; poor process orientation; inadequate decision making; waste and variability in poor work process and conditions. The lack of transparency can increase the chances of error, make problems less visible and decrease the incentive for continuous improvement (KOSKELA, 2000). The lack of process transparency is a factor that can also affect costs during planning and design, which contributes to the construction stage scramble, as described by Klotz (2008). Moreover, the lack of process transparency prevents early-phase stakeholders from identifying the impacts that their decisions have on the final product, contributing to delays and major cost impacts in all phases of project delivery (KLOTZ, 2008)

By contrast, when the process visibility is not supported by an adequate managerial development, it can also lead to hidden issues to maintain privacy, facilitating the reduction of transparency. Bernstein (2012) argues that a greater observation can be perceived through the removal of physical barriers, e.g. walls; however, this does not mean that transparency will be achieved. According to Bernstein (2012), increasing the observability of a workspace can be associated with the reduction of transparency in some cases, since it can be replaced by illusory transparency and can create a hiding behaviour in workers.

3.2.3 Transparency and ICT

The visions and rhetoric related to IT in construction have turned out to be distant from the reality of ICT usage in this context (KOSKELA, 2000). Over the years, construction information and communication technologies have been observed in the literature (KOSKELA, 2000; DAVE et al., 2008; TEZEL; AZIZ, 2017). According to Koskela (2000), ICT can be very helpful, along with all the associated promises of visualisation and simulation; therefore, process transparency, when aided by a computer, can support in the implementation of operations management principles. However, both simulation and visualisation, when used and implemented in isolation, tend not to be effective in terms of increasing process transparency, as the conventional management does not emphasize the transparency concept (KOSKELA, 2000).

Many companies consider computers and ICT as a solution to information deficits. However, as discussed by Formoso, Dos Santos and Powell (2002), computers only partially support the solution of getting information in and out of the production. Galsworth (1997) argued that even if computers can provide the information needed, they are usually successfully used for individual communication, as they lack a public interface for group communication. Nicolini (2007) also investigated sophisticated computer interfaces, questioning to what level such interface can facilitate or hinder collaboration, since it can prevent or limit people from freely modifying its content (NICOLINI, 2007). Nonetheless, computers can play a larger role in visual systems when they offer expanded visibility (GREIF, 1991).

3.2.4 Autonomation and process transparency

Autonomation is a concept very much related to process transparency. It has been pointed out as one of the columns of the Toyota Production System (TPS) and, originally, came from the word *Jidoka,* which means automation with a human touch, i.e. people have autonomy to stop when there is a problem (LIKER, 2004). It is also directly related to the idea of keeping quality as workers produce parts (LIKER, 2004). According to Ohno (1988) and Liker (2004), autonomation means giving autonomy and empowering workers, allowing them to identify abnormalities and failure during the process, to stop production when needed and to encourage the assessment of the problem and implementation of corrective actions.

According to Liker (2004), as a result of the implementation of autonomation, the entire team becomes responsible for the quality of the product and feels valued. This is one of the mechanisms for supporting continuous improvement, with the aim of hiking a continuous production flow without failures or variability (OHNO, 1988). Autonomation has also been described as a practice to determine the best way to perform a task, based on the definition of a standard method (HOPP; SPEARMAN, 2004). In manufacturing, visual inspection is one of the practices that allow workers to have greater autonomy to control their own machines (KJARTANSDÓTTIR, 2011). Likewise, in construction this type of system is also used, such as Andon, which can signal when a line was stopped by an operator (MOURÃO; VALENTE, 2013). This type of visual system, in general, is focused on conformance, due to the difficulty of finding defects before installation (KJARTANSDÓTTIR, 2011).

3.3 VISUAL LANGUAGES AND VISUALISATION

Valente (2017) argues that recent publications related to visual languages address concepts as knowledge visualisation, visualisation management and collaborative visualisation dimensions, which can support the implementation of VM. Visual language is described as a set of visual sentences related to human-computer interactions, divided into components: signs and image (pictorial aspect), its logical description and the relationship between the pictorial elements and the computational meaning (BOTTONI et al., 1998). It can also be described according its functions, such as graphic, syntactic and semantic attributes (COSTAGLIOLA; DELUCIA; OREFICE, 2002).

According to Zhang (2012), the representation of visual communication information between humans and machines is considered a visual language, which creates conditions for a quick and effective communication through visual perception. Killen and Kjaer (2012) address benefits related of the adoption of digital tools combined with human capabilities, such as: (i) support the creation of visual representations through a new way of data collection, reducing bias that can be introduced in face-to-face relationships; (ii) new way of displaying data; (iii) flexibility in use; (iv) acceptance and usability of tools and information.

Visualisation, static or dynamic, is also classified as a type of visual language to represent sophisticated concepts or a set of data in two or more dimensional forms (ZHANG, 2012), which can assist in the management of information in decision making, knowledge and learning sharing, idea generation and planning (EPPLER; BRESCIANI, 2013). Therefore, visual languages can support strategic decision making, enabling the consideration of several factors and the visualisation of future alternative, that is, they are able to elucidate complex relationships, understand historical events and analyse the various factors involved (KILLEN; KJAER, 2012). Killen and Kjaer (2012) investigated the development and application of methods and tools for managing project interdependencies and how visualisation can assist in their understanding. According to their analysis, cultural factors may have more influence than process factors in understanding the project's interdependencies.

The ability of some information to be cognitively processed through its visualisation improves the analysis, since it can preserve the spatial orientations and the interrelationships between different components – contrasting with other types of information, such as numerical and verbal, which do not present this capacity (KILLEN; KJAER, 2012). Thus, there is an increasing adoption of qualitative visualisations (conceptual diagrams, for example) in the management tasks (EPPLER; BRESCIANI, 2013). Visualisation is considered a means to enable effective collaboration, especially across disciplinary boundaries (EPPLER; BRESCIANI, 2013).

For Zhang (2012), both visual means and graphics in a visual language can help to maximise visual perception so that communication can be quick and effective in management. However, according to Zhang (2012), the visualisation of management activities has been limited to stereotypes or statistical charts, which do not communicate complex relationships, and present an apparent lack of intuitive visual languages used within an innovative way.

3.3.1 Collaborative visualisation

Visual representations allow the understanding of the result of multiple interactions and connections across people and process over time, as defined by Whyte, Tryggestad and Comi (2016). Collaborative visualisation systems aim to create a common knowledge base or a shared cognition (YUSOFF; SALIM, 2015). Collaborative dimensions of visual representations were created to understand how information is used as a collaborative tool and their effects, describing the main features of a visual language and defining whether it is suitable for a management task (EPPLER; BRESCIANI, 2013). Eppler and Bresciani (2013) defined the dimensions of visual representation, e.g. visual impact, clarity, and directed focus.

According to Eppler and Bresciani (2013), visualisation generates more value to the final product when it is used as a collaborative tool between those involved, which is also called as a catalyst tool. Isenberg et al. (2011) described the collaborative visualisation into three levels of engagement of teams, which aim at a common understanding. The levels are described as (i) viewing; (ii) interacting and exploring; and (iii) sharing and creating (ISENBERG et al., 2011). Visualisation is described by Isenberg et al. (2011) as a level of engagement which can support a group of stakeholders to view static or dynamic information without being able to interact with them. Exploring is described as a level of engagement among a group of people who share the same visualisation tool interactively and are able to create/share new information (ISENBERG et al., 2011). Sharing category is allowing many people to create, upload, and share new datasets and visualizations (ISENBERG et al., 2011).

3.3.2 Shared understanding through visualisation

It is important to understand the complex relationship between visual management practices and cognitive process of users, considering visual tools can facilitate the cognitive processes of understanding, as well as the cognitive process can influence on best visual practices (VALENTE; BRANDALISE; FORMOSO, 2019). Nicolini (2007) states that it is necessary to understand the visual tools in use, introduced in the context, and processes through a systematic approach. However, shared visual representations raise concerns among researchers regarding how knowledge is captured, represented, displayed and analysed by all users involved (YUSOFF; SALIM, 2015).

Collaborative and shared tools can present the ability to act as a boundary object, responding to different concerns simultaneously, being adopted as a common reference point among users and allowing greater interaction and coordination among them (NICOLINI, 2007). According to Nicolini (2007), boundary objects are transported in time and space, legitimising decisions and mediating different interests. Each group of users assigns meaning according to their experiences and mental models, not being necessary for those people to create the same meaning of how they think, feel or see that object; however, the object maintains the relationship and cooperation among the users (NICOLINI, 2007). From this perspective, collaboration, trust and partnership are seen under an innovation vision, in which a combination of factors, such as willing people and adequate processes/artefacts, are essential for those concepts to be sustained in practice (NICOLINI, 2007).

According to Yusoff and Salim (2015), shared boundary object is a strategy that allows knowledge to be integrated among several users, who can present different objectives, considering an unique object of analysis. Yusoff and Salim (2015) describe different functions of boundary objects: (i) speaking, allowing the selected information to be represented and integrated; (ii) thinking, giving support to develop, clarify and assist the structuring of data and arguments; (iii) coordinating perspectives and actions, helping to compare perspectives, relating different domains of knowledge and allowing joint activity, for example. There is a need to explore the challenges and barriers of such objects connected with ICT based solutions in organisations that have distributed teams (LINDLÖF, 2014).

3.4 VISUAL MANAGEMENT TAXONOMIES

The VM tools can be classified into different taxonomies. Galsworth (1997) describes a taxonomy of visual management practices according to the degree of control (see Figure 10).

Figure 10 – Control levels – types of visual tools.

Visual indicator	Visual Signal	Visual Control	Visual Guarantee
No power, provides information, it is a passive tool, adherence to content is elective	Some power, it draws attention and then delivers the message, the tool tends to be more active, uses visual stimuli.	Significant power; it impacts on behaviour; the tool has the potential to restrict choices with physical limits.	Absolute power; it restricts behaviour; error-proof tool, programmed to minimize human error

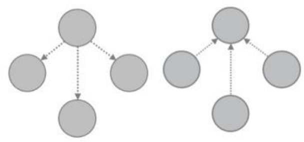
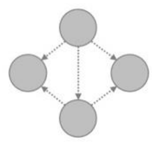
Source: adapted from Galsworth (1997, 2017).

Visual indicator and signals refer mostly to the receivers' behaviour, but there is not necessarily adherence to the tools. Whereas visual, control and guarantee categories emphasize the importance of the adherence to the information transmitted, as well as automatic transfer through the tool itself. The four degrees of control are described in detail, according to Galsworth (1997, 2017): (i) visual indicator can be characterised as a tool to provide passive messages, as it only informs, e.g. road sign; (ii) visual signal, similar with the previous classification, it also provides a message, e.g. traffic lights; (iii) visual control impacts the user's behaviour, having the potential to restrict future action through size, number, height, e.g. parking lines; (iv) visual guarantee allows only the correct answer by incorporating the exact information in the design process, e.g. poka-yoke.

Galsworth (2017) refined the taxonomy previously proposed, describing what visual patterns would be visual tools and visual metrics. Visual patterns define what is supposed to happen. Visual tool presents the characteristic of the information (what, when, where, etc). Visual metrics are related to performance feedback. In addition, visual tools are able to deal with the information deficit in situation where the message is shared in an inaccurate and incomplete way, being classified according to the location or specification (GALSWORTH, 2017).

Valente et al. (2019) categorised VM tools according to the maturity stages: (i) performance evaluation and activity coordination; (ii) reflection, planning, and decision making; and (iii) collaboration. Brandalise (2018) also proposed a taxonomy of VM practices, considering three main categories of communication and integration: (i) one-to-one, (ii) one-to-many or many-to-one, and (iii) many-to-many (Figure 11). This taxonomy provides an understanding of how information is shared between participants, identifying the way that communication occurs between information senders and receivers, and the integration of the VM practice to the management routines.

Figure 11 –Taxonomy of advanced practices of VM systems

One-to-one (OO)	**One-to-many or Many-to-one** (OM or MO)	**Many-to-many** (MM)
Clear channel of communication between a sender and a receiver. Collaboration may occur in the design of the VM tool, but it is not widely observed in its use. Low level of integration with management routines. Ex.: Andon, Kanban, and poka-yoke.	Practices that coordinate activities of many stakeholders, allowing data sets to be analysed concurrently to produce routine information prior to decision making. Intermediate level of integration with management routines. Ex.: customization marking, and target dates of production decided collaboratively.	Enable communication and decision making between many users and between departments, using highly dynamic VM practices as support. Highest level of integration with management routines. Ex.: board of shop floor management, and prototypes.
		

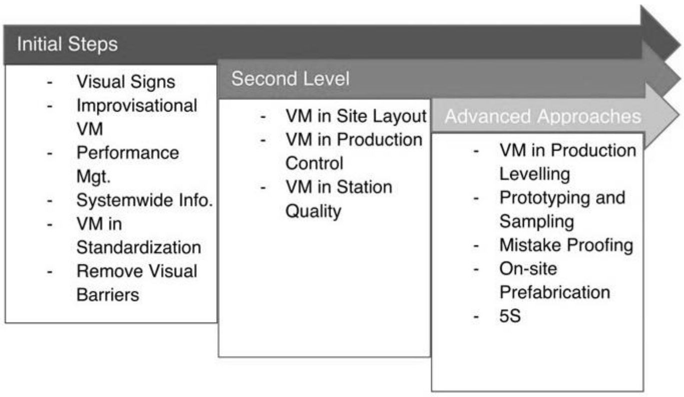
Source: adapted from Brandalise (2018).

Another categorisation often adopted is open (unfrozen) or closed (frozen) visual devices (NICOLINI, 2007; WHYTE et al., 2007; EWENSTEIN; WHYTE, 2009). Bititci, Cocca and Ates (2016) named those categories as dynamic and static, considering the type of visual expression. There are positive and negative impacts of both types: while an open nature tool is beneficial in bringing people together and generating discussions around it, it may not be positive for other purposes (NICOLINI, 2007). According to Nicolini (2007), the inappropriate use of visual tools can generate unexpected and unwanted interactions.

Tezel (2011) identified 9 different functions of Visual Management, based on literature review, which are: (i) transparency; (ii) discipline; (iii) continuous improvement; (iv) job facilitation; (v) on-the-job training; (vi) creating shared ownership; (vii) management by facts; (viii) simplification; and (ix) unification. The transparency concept was explained in the previous sections. The discipline is supporting the creation of habits of properly maintaining correct procedures (HIRANO, 1995 apud TEZEL, 2011). The function of creating a shared ownership is related to the feeling of being psychologically connected to an object (PIERCE et al., 2001 apud TEZEL, 2011). The simplification is essential to avoid poor performance, waste, misunderstandings, created by information deficiencies or information overflows. The unification is described as partially eliminating the four major boundaries (vertical, horizontal, external and geographic) and developing empathy through effective information transfer. The unification concept can also be related to the collaboration.

Tezel et al. (2015) refined the taxonomy previously proposed in which visual management practices are classified according to their purpose, method of application and management goals: (i) VM in systematic site order; (ii) VM by removing visual barriers; (iii) VM for standardised identification and location; (iv) VM in production control; (v) VM in production levelling; (vi) VM in prototyping and sampling; (vii) VM in-station quality; (viii) VM in work facilitators; (ix) VM in site signage; (x) improvisational VM; (xi) VM in performance management; (xii) VM in mistake proofing systems; (xiii) VM in distributing system wide information; and (xiv) VM in on-site prefabrication. Tezel et al. (2015) identified different levels of implementation, which can be designed by companies in a logical sequence (Figure 12). The level starts with initial steps, e.g. basic site standardisation and order, and moves on to complex visual production levelling and control systems, building levels upon each other (TEZEL et al., 2015).

Figure 12 - Levels of VM implementation



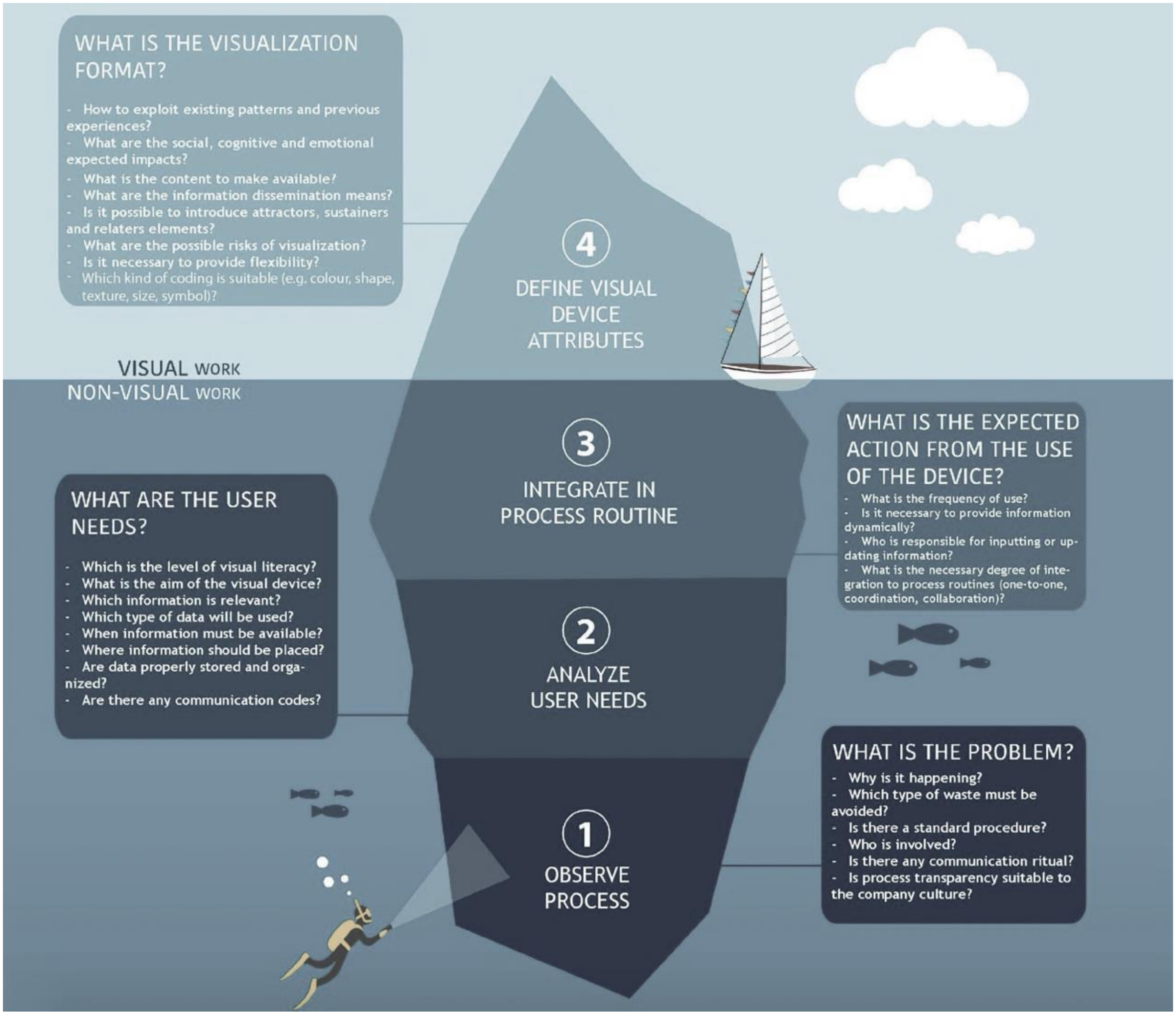
Source: Tezel et al. (2015)

3.5 IMPLEMENTATION OF VISUAL MANAGEMENT

According to Tezel, Koskela and Tzortzopoulos (2016), the creation of tools must be justified at a strategic level, but it is not possible to guarantee that a tool designed for a specific activity does not create problems for other processes and sectors, so it is important to analyse the context in which it is applied. Therefore, understanding the function of each tool is essential, as different solutions may be needed in different organisational realities and contexts (TEZEL; KOSKELA; TZORTZOPOULOS, 2016). According to Tezel, Koskela and Tzortzopoulos (2016), the functions can be used as a conceptual basis for the evaluating the realisation degree related to the VM strategies implementation.

Valente (2017) proposes a model devising visual management systems within the integration tools, people and processes in construction industry, which is represented through the iceberg metaphor (Figure 13). The aim of the model is a prescriptive contribution, e.g. supporting companies that intend to develop or refine visual management systems in the production management within construction projects. The iceberg metaphor assumes that only a portion (the visible one) of the VM practice is effectively related to the visual work, as described by Nicolini (2007). This model can be used to support the development and evaluation of VM systems, being divided into four phases: (1) observation of the process, (2) analysis of the users' needs, (3) integration with the process or routine, (4) characteristics of the visual tool.

Figure 13 – Model for devising visual tools for production management in construction



Source: Valente (2017)

Information exchange in planning and control can be supported by VM (BRADY et al., 2018). VM practices applied systematically, during planning and control, aim to facilitate collaboration and allow greater consistency between the levels of hierarchical planning, since the objectives become connected and aligned (BRADY et al., 2018). Thus, Brady et al. (2018) argue that VM practices have the potential for exchanging and handling information among different hierarchical levels. Brady et al. (2018) also described other two reasons for a systematic adoption in planning and control, which are: (i) supporting continuous improvement, and (ii) motivating participant and develop trust.

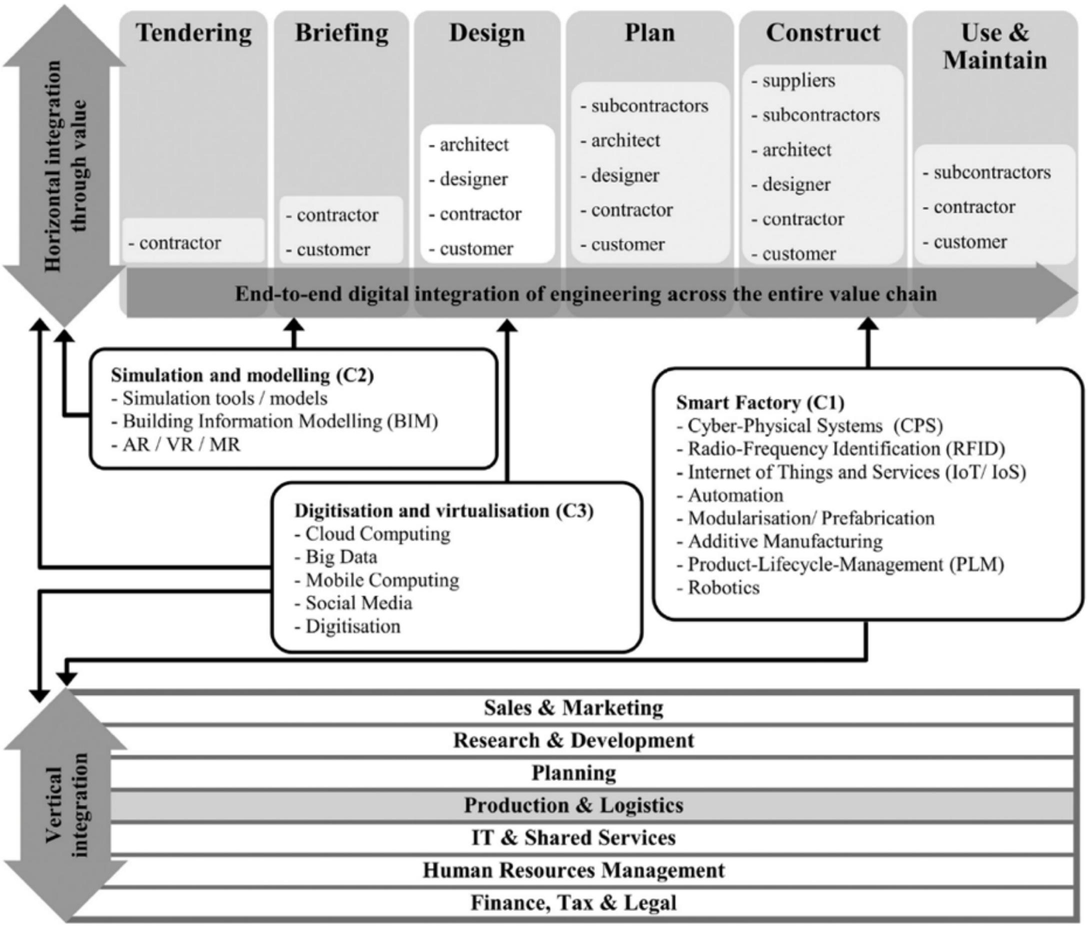
The model proposed by Brady et al. (2018) classifies production planning and control into three processes: (i) the overall process analysis (OPA) phase, e.g. overall process map; (ii) the process planning (PP) phase, e.g. process planning tool and KPIs; and (iii) the detailed planning (DP) phase, e.g. planning boards and KPIs, facilitating a visual connection of information among the different levels. Visual tools provide physical aids to the flow of information on the project, with the aim of making both plans and actual work in progress transparent to participants.

3.6 INFORMATION MANAGEMENT AND DIGITALISATION

There is a need to integrate processes, people and technology in order to find solutions to manage information and to achieve benefits of the available systems (LAINE; ALHAVA; KIVINIEMI, 2014). Teams have to become more collaborative and proactive in digital design environments, and design information becomes more explicit than ever (DEN OTTER; PRINS, 2002). Formoso, Dos Santos and Powell (2002) also recognised the need of innovative use of ICT and electronic tools to support flexible and less time consuming measurement techniques. According to Tezel and Aziz (2017), digital scenarios of VM can be extremely dynamic, incorporating automation and several perspectives from different disciplines members.

The impact of technologies on the construction value chain is investigated by Oesterreich and Teuteberg (2016) (see Figure 14). The major findings show that current research is mainly focused on exploring technical aspects of technologies, whereas economical, ethical or environmental, and socio-cultural aspects persist widely unexplored (OESTERREICH; TEUTEBERG, 2016).

Figure 14 – Impact of Industry 4.0 technologies on the construction value chain



Source: Oesterreich and Teuteberg (2016).

Three dimensions of the value chain are investigated within the Industry 4.0 concept, considering specific characteristics of the construction industry: (i) horizontal integration within value networks, as a consequence of the increasing number of stakeholders involved in the entire value chain; (ii) end-to-end digital integration of engineering within the use of technologies across the value chain; (iii) vertical integration, which is related to the integration of processes, information flows, IT systems with the implementation of virtualisation and digitisation technologies or integration of automation technologies (OESTERREICH; TEUTEBERG, 2016).

3.6.1 Benefits and challenges of VM and ICT integration

Information management benefits from advances in information and communication technology, as it allows greater speed in the flow of information, greater effectiveness and efficiency in communication and reduction is the cost of transferring information (CHEN; KAMARA, 2008). However, Laine, Alhava and

Kiviniemi (2014) argue that it is more difficult to apply the principles of VM to information flows in digital systems. Therefore, noticing the waste in the information management system is more challenging when compared to the management of material flows (LAINE; ALHAVA; KIVINIEMI, 2014).

Laine, Alhava and Kiviniemi (2014) explored an innovative way to improve information management and information sharing within a project team, and the solution proposed by the authors considers the combination of Lean and BIM principles. The use of BIM allows certain activities, which do not add value to the product and the process, to be automated or eliminated (TEZEL; AZIZ, 2017). The use of standardised model helps to reduce time in the search of data, in a more consistent and updated information delivery, as well as provide only the information needed within an easily understandable and visual format by using mobile solutions at the right time and in the right place, e.g. tablet computers (LAINE; ALHAVA; KIVINIEMI, 2014).

Tezel and Aziz (2017) argue that making information available can support cost and time savings, since the access to relevant information is quick, easy and accurate through a better understanding of the user's context. Information contained in visual construction models, for instance, can be used to effectively support critical decision making in the process and assist in the development of standardised visual management interfaces (TEZEL; AZIZ, 2017). Tezel and Aziz (2017) also argue that adoption of IT to support VM and lean construction presents some opportunities, as: (i) intensifying technology integration efforts; (ii) decreasing the costs of technology implementation; (iii) raising awareness related to certain technological components and tools.

Also, Tezel and Aziz (2017) identified that visual management systems with ICT support can provide automated and shorter information feedback, as well as support data collection as a way to integrate ICT systems with all stakeholders and, thus, improve the flow of information. The ease of use in aspects of internet-based ICT tools for the management of architectural design teams, as well as the accessibility and transparency of the stored information can be very effective in the process of decision making and documenting decisions in the very early design phase (DEN OTTER; PRINS, 2002).

Besides the economics benefit supporting the increase of productivity, quality, collaboration and efficiency, there are economic, social, political, environmental, technological, and legal challenges that have to be embraced (OESTERREICH; TEUTEBERG, 2016). Organisations have to deal with process changes, high costs of implementation and maintenance of the system, necessity of data protection and security (OESTERREICH; TEUTEBERG, 2016; TEZEL; AZIZ, 2017; MURATA, 2018). Oesterreich and

Teuteberg (2016) also argue that the employees need to handle with rising job demands and higher level of mental issues and stress (considering the potential job losses related to the digitalisation). The technical issues identified are mostly related to the (i) lack of standards for the variety of technologies; (ii) requirements for computing equipment, and (iii) increasing demand for improved communication networks (OESTERREICH; TEUTEBERG, 2016).

According to Tezel and Aziz (2017) the implementation of technology still presents some threats, e.g. neglecting the process and people, and giving too much importance on the technology side; deficient supply chain readiness to implement and operationalise the digital scenarios; lacking of client or top management support; increasing the dependency on technology. Some barriers faced by the implementation of technology may be related to the lack of interoperability among technologies, lack of trained workforce, and lack of best practices and business case (TEZEL; AZIZ, 2017).

Murata (2018) pointed out that visual management will not be fully digitalised in the future. Informal and verbal communication are still considered important in the very early design phase, supporting the creation of a mindset about the design (DEN OTTER; PRINS, 2002). Items related to communication, team building, and information sharing should be better visualised by traditional tools, according to Murata (2018).

The use of a digital visual system may generate negative impacts and hidden problems, among them, waste and omissions of visualisation can be highlighted (EPPLER; MENGIS; BRESCIANI, 2008; MURATA, 2018). Murata (2018) describes the waste of information as elements and visual information in excess, which can generate misunderstandings and errors of judgment and interpretation; while the omission of information is related to the problem of maintaining a digital network and the difficulty of selecting information relevant to the process. Challenges in the information flow between stakeholders lead to low transparency and restricted communication (DALLASEGA; RAUCH; LINDER, 2018). Likewise, the simplicity intrinsic to visual tools should be considered in the digitalisation of tools, as they should support easy access to information.

3.6.2 Implementation of VM and ICT

Several studies have analysed future scenarios for the implementation of those practices considering a lean perspective. ICT has contributed to extend the range of VM applications (see Figure 15), which are: (i) visibility, through an improvement in the power of representation with the interface innovation; (ii) temporal capacity through information accumulation and analysis; (iii) ability to solve problems with the support of automation in the information processing (artificial intelligence, for example); and (iv) capability to cross geographical boundaries through high connectivity (MURATA, 2018).

Figure 15 –Traditional and digital visual management

Attributes	Traditional Visual Management	Digital Visual Management
Clarified item by visual tools	Clarifying what is normal and what is abnormal (Ohno 1988)	Clarifying the internal and external risks that threaten the survival of a company
Visualised item	Visualising vital objects, activities, and indicators	Visualising al objects, activities and indicators
Idea source of visual tools	Diverse idea-driven visual tools for a plan view	Data – or virtual – visual tools, such as a sensor, an analytical tool, a control tool, and a display with coming and going from real world to data world
Establishment of visual tools	Distributed in a production system	High connectivity among all managed objects for perfect problem-solving with crossing geographical and temporal boundaries

Source: Murata (2018).

Tezel and Aziz (2017) also created a scenario for the implementation of visual management considering the lean concepts perspective and emerging information and communication technologies systems. The integration of information requirements with interactivity and context awareness aspects, which is described as the user location and involvement in specific tasks, can be achieved in visual management systems by increasing the level of automation (TEZEL; AZIZ, 2017). Tezel and Aziz (2017) argue that technologies should be supported by cultural changes and improvements in the company's business process, competences and skills.

3.7 CORE CONSTRUCTS

Figure 16 summarises key constructs on ICT based on visual management identified in the literature review, and a brief description of each of them. Those constructs are related and depend on each other to support the adoption of digital VM.

Figure 16 – Initial set of VM requirements for design planning and control within digital contexts

Concepts	Brief description
Simplicity	It is one of the most essential concepts of VM. VM tools are developed to be simple to use and understand, so the information transfer provides autonomy to stakeholders (LIKER; HOSEUS, 2009). This simplicity is related to the use and functioning of a VM tool, as argued by Saurin, Formoso and Cambraia (2006), allowing easy changes to be made. It is associated with an easy understanding (VALENTE; BRANDALISE; FORMOSO, 2019) of the tool objectives.
Information Standardisation	According to Laine, Alhava and Kiviniemi (2014), information standardisation can assist in the reduction of time in data searching, as well as deliver up-to-date and more consistent information, providing only the information required (TEZEL et al., 2015; TEZEL; KOSKELA; TZORTZOPOULOS, 2016). It can also avoid misunderstandings, preventing loss of time to understand and interpret information (ALARCÓN; MARDONES, 1998).
Information availability	Information should be 'pulled' by any member at any time, not following a linear flow (GREIF, 1991; SACKS et al., 2010; LEE, 2018). Early availability of information or excess of information can lead to excess production; which outlines the essential character of pulling information when required (OHNO, 1988), i.e. the availability of the right information for the right purpose at the right time. Easy information accessibility supports data gathering and processing (TEZEL; KOSKELA; TZORTZOPOULOS, 2016), facilitating the capture of relevant information for each specific context and process. VM tools should be easy to access and to update (VALENTE; BRANDALISE; FORMOSO, 2019).
Flexibility of tools	This concept is related to the flexibility to make changes in the tools as needed (BARTH; FORMOSO; STERZI, 2019). Visual tools can be modified through dynamic interactions (EPPLER; BRESCIANI, 2013). For instance, customisable interfaces of tools can better deal with context specifications or with unexpected changes in the environment. It is necessary also to consider the adaptability of information to different users and contexts. VM tools are considered as means of communication between individuals with different perceptions which work collaboratively which need to establish a common point of view (LINDLÖF, 2014). Also, an agile response to the emergent new tasks can be potentially be adopted through visual tools (DAOU et al., 2015), which requires real-time and dynamic interactions. It is related to mobility, dynamic information display within complex information flows, shorter information feedback (TEZEL; AZIZ, 2017).

Source: the author

4 RESEARCH METHOD

This chapter is divided into five main sections. Section 4.1 describes the research method adopted in this investigation. Section 4.2 presents the positioning of this investigation as Design Science Research (DSR). Section 4.3 describes the exploratory and empirical studies. Section 4.4 provides an overview of the research process. Section 4.5 describes the research process and sources of evidence.

4.1 RESEARCH APPROACH

Yin (1994) suggests that every type of research has an implicit or explicit research design, supporting the logical sequence that relates the empirical data to research questions and its conclusions. The components of a research design are described by Yin (1994) as: research questions, propositions (if applicable), the unit(s) of analysis, the logic connecting the data and the propositions, and the criteria(s) to interpret the findings.

This research adopts the Design Science Research (DSR) approach, which is also known as constructive research or prescriptive science, in opposition to description-driven research related to the natural and social sciences (MARCH; SMITH, 1995). The main results of Design Science Research are prescriptions or artefacts that embody those prescriptions (MARCH; SMITH, 1995). According to Lukka (2003), this research approach consists of the creation of innovative solutions, aiming to solve real-world problems and contribute to the theory of a discipline. Despite having a practical emphasis, DSR also has theoretical contributions to the existing body of knowledge (VAN AKEN, 2004). This research approach is characterised as an iterative process with incremental learning cycles (LUKKA, 2003), in which the problem is understood and the solution is devised.

March and Smith (1995) argue that the design science research can be divided into two major activities: build and evaluate. The first activity consists of developing a solution for a specific purpose, whereas the evaluation is related to the process of assessing the artefact (MARCH; SMITH, 1995), describing the relevance of the solution for the specific purpose and context. It is experimental by nature, considering the artefact developed and implemented should explain, test, or refine a theory, or develop a new theory; based on an in-depth analysis of practice (LUKKA, 2003).

March and Smith (1995) classified the outcomes of DSR into: (i) *constructs* refer to a conceptualisation, or the creation or refinement of concepts, used to describe the problems within the domain and to prescribe potential solutions; (ii) *models* are sets of premises that express connections between the constructs; (iii) *methods* are described as a set of steps (e.g. algorithms or guidelines) adopted to perform a task, based on a representation of the solution space (model) and a set of constructs; and (iv) *instantiations* is the realisation of the artefact within the environment, operationalising methods, models and constructs.

There are three outcomes in this research project, as shown in Figure 17, which are concerned with the adoption of visual management tools in design management within a digital environment. The main artefact proposed in this investigation is a '**set of VM requirements to support design management within digital contexts**.

Figure 17 – Research outputs

DSR Solutions	Research Outputs
Constructs	- Set of VM requirements to support design management within digital contexts.
Model	- Concept map connecting different VM constructs related to design management systems.
Method	- Guidelines for Visual Management implementation in design management using digital tools.

Source: the author.

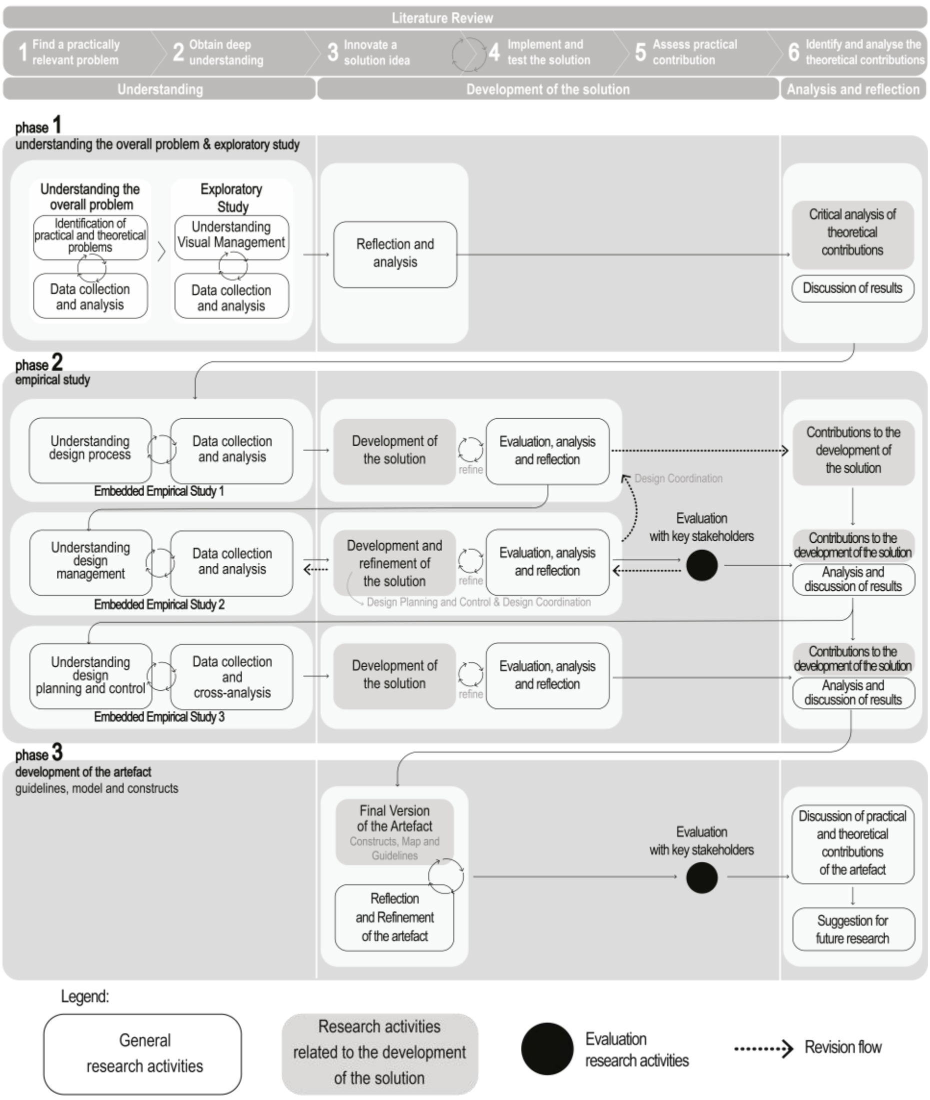
The solution was conceived and assessed in close collaboration with Company A, which was willing to improve its design management process in civil engineering projects. The potential users of the solution are companies and professionals involved in the implementation or improvement of design management processes, such as (i) design team members, team leaders and managers, and (ii) professionals in charge of construction design planning and control.

4.2 RESEARCH DESIGN

Lukka (2003) divides the DSR process in six activities: (1) finding a practical and theoretical relevant problem; (2) assessing research collaboration with the target organisations; (3) obtaining a deep understanding of the problem, considering the practical and theoretical perspective; (4) finding and developing an innovative solution; (5) implementing and testing the solution; and (6) identifying and analysing the theoretical contributions. Holmström, Ketokivi, Hameri (2009), in turn, described the DSR into three main stages: (i) solution incubation (understanding); (ii) solution refinement (development of the solution); and (iii) explanation (analysis and reflection).

This research study was divided into **three main phases**: (i) in **phase 1** an overall understanding and exploratory study were carried out; (ii) in **phase 2** the main empirical study of this investigation was undertaken; and (iii) **phase 3** consisted of the development, refinement and reflection of the final solution. Figure 18 represents the research design described in those three phases, distributed over the **six stages** of the DSR based on Lukka (2003). The phases 1 and 2 can be regarded as two learning cycles, aiming to devise and refine the solution.

Figure 18 – Research design



Source: the author.

The **literature review** was carried out throughout the research study, supporting the entire process. It involved initially two main research topics: (i) Visual Management, and (ii) Digitalisation. During the investigation a third topic, Design Management, was incorporated and explored.

Phase 1 was related to an overall understanding about the key topics of the research, i.e. visual management and digitalisation, through (i) an initial data collection and analysis of direct observations and interviews with experts, and (ii) an exploratory study related to the design development of a retrofit building project. This phase was divided into four stages.

Stage 1 was concerned with the **understanding of the overall problem** through an initial data collection in design companies and with specialists in those topics, whereas a literature review was carried out to identify a knowledge gap. The literature review supported the initial identification and understanding of the problem from a broad perspective, considering different contexts, e.g. design, construction, manufacturing. The real problem identified by the research team in previous studies was also considered as a starting point and it was related to the need of considering the digitalisation integrated within visual management as an approach to support more effective transfer of information.

Stage 2 consisted of the development of an **exploratory study**. The researcher investigated the integration of visual management with digital technologies, also analysing traditional visual tools implemented to compare the traditional strategies within the digitalization. The theoretical contributions were described as discussion of related concepts.

Stage 3 involved an initial data analysis and reflection which explored design information through an analysis of existing digital and analogue visual tools and their integration in collaborative processes. The phase 1 had no activities developed in *stage 4 and 5,* which are related to the artefact development and assessment. The main theoretical contributions of the phase 1 were the initial identification of a set of relevant VM constructs for design management, which were discussed in *stage 6.*

Phase 2 consisted of the development of the main empirical study of this investigation, and three embedded studies, in which there were learning cycles related to the development and refinement of the solution. The knowledge produced in phase 1 was incorporated, enabling improvements in the process and refinement of the theoretical contributions. The aim was to refine constructs, propose guidelines and devise the concept map throughout embedded empirical studies. The empirical study was initially focused on VM, digitalisation and design processes, and then evolved to design management. This research study allowed a better understanding of the adoption of VM tools to support design management in a complex and digital environment. The analysis of both analogue and digital VM tools were essential to better understand the potential benefits and barriers of VM in that specific context. The refinement and evaluation of the contributions were done since the beginning, as the artefact emerged early in the process. The constructs, concept map and guidelines were iteratively refined through consistency analysis with the aim of eliminating potential overlapping of concepts and information.

The **embedded empirical study 1** was divided into five stages. *Stage 1* consisted of understanding the practical problem in the context of the company involved in the study. The starting point was an analysis of the context through a broad perspective of the design process. *Stage 2* focused on the identification of the real problem through initial collection and analysis of data. *Stage 3 and 4* describe the development, evaluation, analysis and reflection of the solution, which were defined as the refinement of VM constructs. This research study did not have an evaluation with the main stakeholders, represented by *stage 5*. Finally, *stage 6* discusses the contributions to the development of the solution, mostly focused on the refinement of constructs, also providing initial insights related to the guidelines for VM implementation.

The **embedded empirical study 2** was divided into six stages and it was characterised as the main embedded empirical study. The largest amount of data was collected and analysed within the Embedded Empirical Study 2, allowing the mapping of management activities and VM tools, and providing an understanding of the design management system based on lean concepts. It was initially focused on the design management processes in *Stage 1 and 2, as* the design process was characterised as a very broad context for this research; besides potential improvements and good practices were identified in the design management segment as a key factor to the company. After the first round of data collection and analysis, the research problem was refined and developed in *Stage 3*, emphasising design planning and control and design coordination. After this definition, the researcher carried out additional data collection and analysis in the embedded empirical study 1 related to the design coordination. *Stage 4* was related to the evaluation, analysis and reflection, related to the design management process and VM tools identified. It was composed of a critical observation about visual tools and their relationship with the digital technologies. *Stage 5* refers to the discussion of the results to evaluate the practical contributions, through external evaluation with the key members from company A and observation of actions as a result of the discussions. Two events were carried out and gave valuable insights for the development and refinement of the constructs, concept map and guidelines. *Stage 6* considers the contribution to the development of the solution, analysing practical and theoretical contributions and discussing the results. It emphasised the constructs and the guidelines for VM implementation in design management.

The **embedded empirical study 3** was divided into five stages. It focused on design planning and control supporting data collected within the previous embedded studies through cross study analysis in *stage 1 and 2*. It allowed an in-deep understanding about the topic through the perspective of a new project, which had plenty of visual management strategies adopted to support design planning and control. It was characterised as a shorter study, however it also contributed to the development, evaluation, analysis and reflection of the solution in *stage 4 and 5*, with discussions related to the implementation of new digital VM tools to support planning and control. Similar to the embedded empirical study 1, it did not have an external evaluation with the stakeholders of the project. At the end of this embedded empirical study, there was a discussion about the main contributions to the solution in *stage 6.*

Phase 3 consisted of the analysis of qualitative data collected in phases 1 and 2, and reflection. The main outcomes of this investigation were produced: the final set of constructs, the concept map and the proposed guidelines. In addition, the main research contributions were made explicit and partially assessed against criteria utility and applicability. The discussion of the practical contributions in external evaluations involved presentations and discussions with key members of the company and experts on the topic. Therefore, the final set of requirements emerged along this investigation, and it was not possible to do an evaluation of its utility and applicability by implementing them in an additional empirical study. This is an important limitation of this research study.

4.3 DESCRIPTION OF THE EXPLORATORY AND EMPIRICAL STUDIES

4.3.1 Exploratory study

This exploratory study was developed as part of an innovation project, entitled "Combining BIM, Lean, and Agile for design management in the development of a retrofit design project", carried out in a partnership between UFRGS and a Brazilian federal public agency, between November 2018 and July 2019. This study was carried out in the initial stages of design development of a retrofit building project in Porto Alegre (see Figure 19), on an important building from the Brutalist Architectural Movement. The main construction project phases involved in this study were (i) building survey of the existing building, (ii) conceptual design development, and (iii) preliminary design development. The researcher acted as a designer and information manager for this project, which was carried out by a team of academic staff, postgraduate and undergraduate students from UFRGS.

The client organization, and also end-user, was the Federal Road Police. However, instead of adopting the traditional Design-Bid-Built procurement form, another model called RDC (Differentiated Contracting Regime) was adopted, due to the project complexity and the architectural value of the building. This model aims to reduce project lead time and cost by transferring the detail design stage to the company in charge of the construction stage. The bidding was based on Law 12.462 (Brasil, 2011).

Figure 19 – Exploratory study description

Project description	
Description	Design development in construction sector
Location	Porto Alegre, RS - Brazil
Project scope	Development of building survey, conceptual and preliminary design of an existing building
Project duration	24 weeks
Project team size	32 members
Client/End-user	Federal Road Police
Size of the project	13.700 sq.m.
Activities analysed	Design development (conceptual and preliminary design stages), building survey and requirements management
Analysis focus	Team A perspective (the researcher was involved with this team)

Source: the author.

The project can be described as a building retrofit, as it was necessary to adapt an existing building to new uses and client requirements. The retrofit project included both adjustments to current regulations and changes in layout, façade and infrastructure. The building survey and design development were formed by five major disciplines, i.e. architectural design team (A), structural design team (B), building service design team (C), building survey team (D) and requirements management team (E). This research study was carried out from the perspective of team A, due to the researcher's involvement in the architectural design. The responsibilities of each team are described in Figure 20.

Figure 20 – Exploratory study: Stakeholders involved in this research study

Teams	Description	Research involvement
Architectural design team (team A)	It was a team of 2 designers, 1 information manager and 2 part-time interns. They were involved in the development of the architectural design building survey and design development. It was also responsible for the technical delivery of the project. Responsible for understanding, managing and curating the design information; produce and/or comment upon project BIM Execution Plan, exchange information requirements, and coordinate with other disciplines.	Project Meetings, Interview
Structural design team (team B)	The structural design team was responsible for the development of the structure building survey and retrofit proposal. It was a team with 2 structural engineers.	Project Meetings
Building service design team (team C)	The building service design team was responsible for the electric and hydraulic building survey and project development. This team was also responsible for the fire prevention project. It was a team with 4 engineers.	Project Meetings
Building quantity survey team (team D)	The building quantity survey was responsible for the financial proposal and it was a team with 1 civil engineer and 1 intern.	Project Meetings
Requirements management team (team E)	This team was responsible for capturing and modelling the client requirements, also for managing and coordinating 3D Model and requirements management; liaising with the client to agree requirements.	Project Meetings

Source: Company A.

This project had a very short development time (6 months), it can be regarded as having a high level of complexity, due to the large number of components and interdependences (structural complexity), and uncertainty (retrofit project). Considering the nature of the project, the decision was made to adopt Lean principles, Agile Project Management and BIM as key approaches. Lean and Agile were used to support design planning and control, aiming to (i) manage a high level of uncertainty and structural complexity, (ii) consider financial constraints, (iii) deal with tight deadlines, (iv) manage collaboration of a large number of stakeholders, and (v) support a reliable design process. BIM was implemented as an approach to support design development and coordination within tight deadlines, and also client requirements management.

The study presented limitations as it was focused on two specific stages of the design processes (conceptual and preliminary design), a limited number of disciplines were involved in the Exploratory Study, and it was carried out within a university extension project, which had some context limitations.

4.3.2 Empirical study

The main empirical study was carried out in an infrastructure design company (company A) from the UK, and it was considered a phase of in-depth analysis and understanding through some descriptive research. This company operates in highways and railways construction projects, being chosen due to the fact that it implemented several Lean practices and also digital tools to support the design process. This phase was developed between August 2019 and May 2020. The description of the empirical study is summarised in Figure 21.

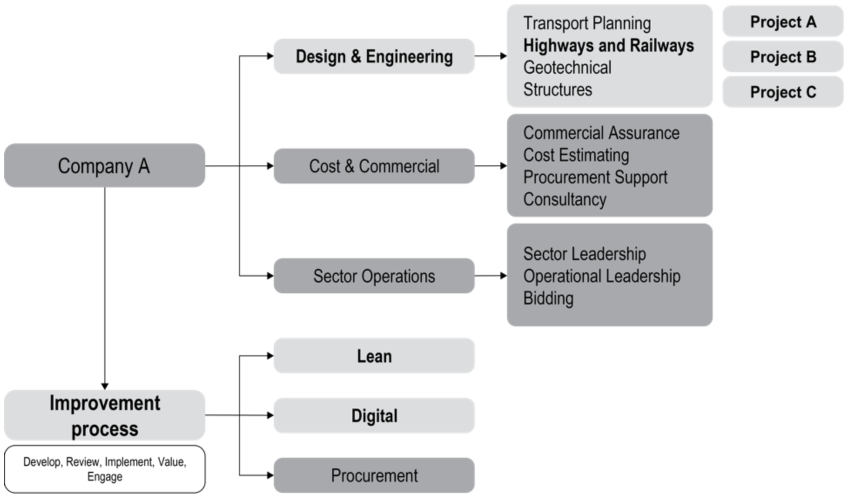
Figure 21 – Empirical study description

Empirical study description	
Description	Design management of infrastructure projects
Sector	Civil engineering
Location	UK
Scope	Highways projects (project B and C) and highways sector of a railway project (project A)
Empirical study duration	32 weeks
Activities analysed	Design planning and control, design coordination
Analysis focus	All projects are analysed according to the perspective of Company A, even when they are a joint venture with multiple companies

Source: the author.

The company was engaged in a process improvement programme in its Highways Division, based on lean thinking and practices, and digital improvements (Figure 22), and provided an opportunity for the involvement of the researcher in this programme. Data from three different projects (project A, B and C) were analysed in this investigation, which are entitled in this research as Embedded Empirical Studies 1, 2 and 3. Those projects were undertaken by the design and engineering sector of the company, being concerned with highways projects (project B and C) and the highways part of a railway project (project A) (see Figure 21 and Figure 22). The projects were chosen as empirical studies due to (i) the availability of the teams to participate in the research; (ii) the variety of project scope and size; (iii) identification of good practices related to Lean thinking and digital technologies. Project A's client was different from projects B and C client; consequently, the design process had differences in the structure of phases and deliverables (see sections 4.4.2.1 to 4.4.2.3).

Figure 22 – Empirical study: Company sectors.

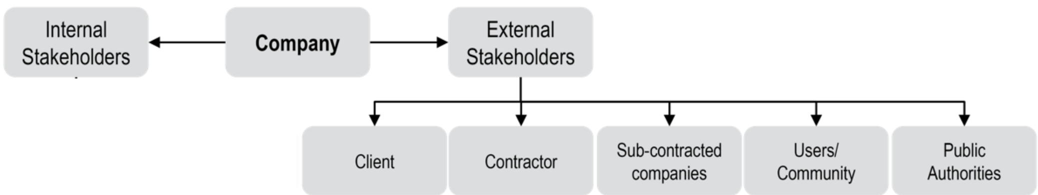


Source: the author.

The design projects carried out by Company A had a high level of complexity, due to a multitude of internal and external stakeholders and a large number of interdependencies between them (Figure 23), and a high degree of uncertainty, as the process had to be adapted according to client's requirements and to singular process specifications related to the organisations involved. There was both organisational and technological complexity, as described by Williams (1999), considering that the interdependences were related to the organisational elements as well as to activities and tools.

The main external stakeholders were client organisations, contractors, sub-contracted companies, users or community representatives, and public authorities (see Figure 23). The client organizations were government-owned companies in charge of operating, maintaining and improving highways and railways in the UK.

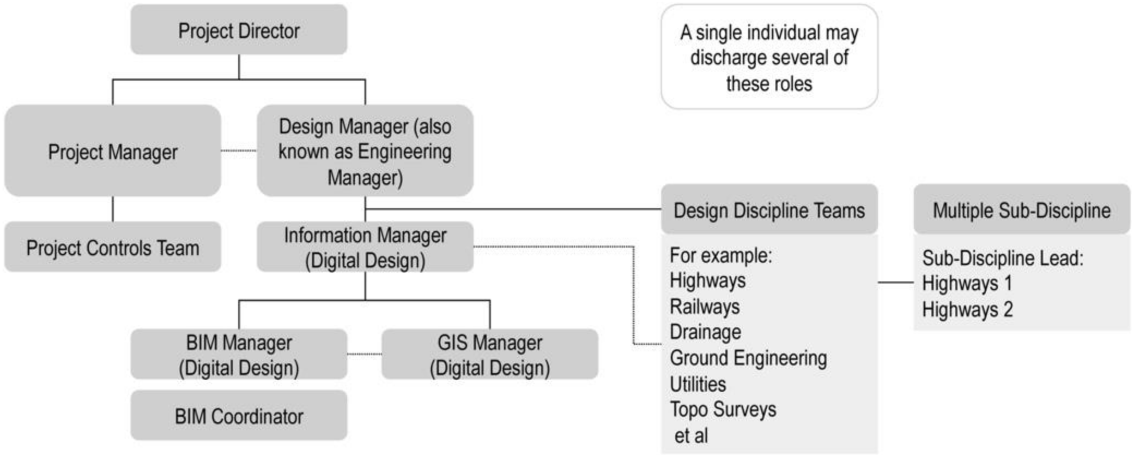
Figure 23 – Empirical study: Company's stakeholders.



Source: the author.

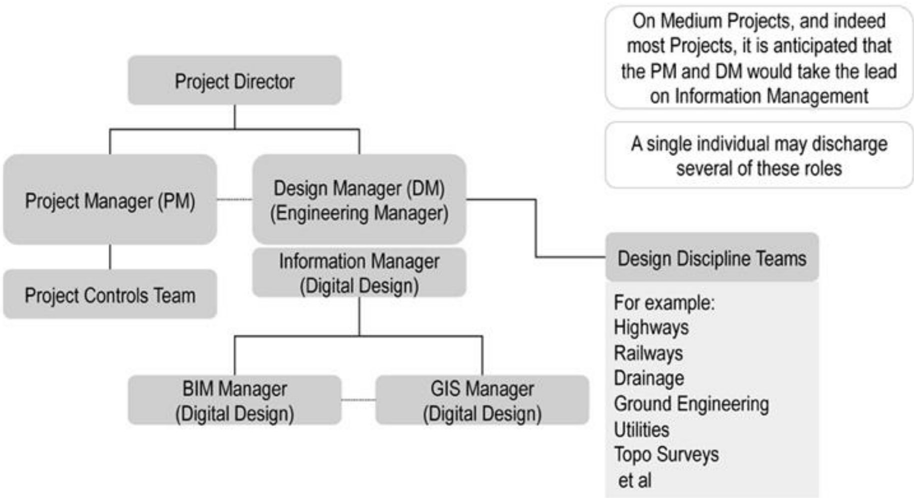
The internal project structure was organised according to the project size. All projects required the following roles: project director, project manager (PM), project control teams, design manager (DM), information manager, BIM and GIS manager, and design team leaders and members. Large projects, such as project A (embedded empirical study 1 – EES1) and C (embedded empirical study 3) also had multiple sub-disciplines (e.g. highways 1 and highways 2), see Figure 24. Project B (embedded empirical study 2) was classified as a medium project, and the organisation structure was simpler than project A and C, as it did not consider multiple sub-discipline (Figure 25).

Figure 24 – Empirical study: Organisation structure (large projects) – EES1 and EES3.



Source: Company A.

Figure 25 – Empirical study: Organisation structure (medium projects) – EES2.



Source: Company A.

The key stakeholders involved in the research project are described according to their role, main responsibilities and their involvement in this research study, i.e. which type of data they provided (Figure 26).

Figure 26 – Empirical study: Stakeholders involved in this research study

Role	Description	Research involvement
Business Director	Accountable for a portfolio of projects, which is linked to specific clients or specific services, and also accountable for client satisfaction and project performance for every project in their unit.	Meeting
Technical Director	The technical director is a key and strategic member of the team and helps to drive the business forward.	Meetings, Interview, Workshop, Project Meetings
Performance Manager Associate Director	Responsible for planning or organizing day-to-day affairs in a particular performance management area of the company or project.	Meeting
Senior Consultant	Responsible for supporting the improvement of business performance in terms of operations, profitability, management, structure and strategy.	Interview, Project Meeting
Project Director	Accountable for overall project objectives and project design quality. Direct and oversee the delivery of the project using an effective review process, ensuring compliance with organisational processes and procedures whilst meeting quality and budgetary targets.	Project Meetings
Project Manager	Responsible for the overall project objectives, project cost and schedule. Accountable for managing, communicating and sharing all project control information across the project.	Interview, Workshop, Project Meetings
Design Manager	The Design Manager is responsible for the technical delivery of the project to time, budget and to the right quality.	Project Meetings
Information Manager (Digital Design)	Responsible for managing, communicating and sharing all project control information across the project, for the development & integration of 3D Model and Drawings, and for the development of GIS viewers and management of GIS data.	Interview, Project Meetings
Team Leaders	Team Leaders run teams of 8-12 people. Their role is to lead the development of their team members, setting annual objectives through the process and measuring performance against them.	Project Meetings
BIM Manager	Responsible for the development and integration of 3D model and drawings.	Meeting, Interview, Project Meetings
GIS Manager	Responsible for the development of GIS viewers and management of GIS data.	Project Meetings
Team member	Responsible for the design development and processes within each highways discipline.	Interview, Project Meetings
Technical Consultant	Responsible for the technical aspects of the scheme, looking at all the potential possible options available and technical appraisal of those options.	Interview, Project Meetings
Risk Manager	Responsible for communicating risk policies and processes for the organisation or a project.	Interview, Project Meetings
Client Representative	Formally represents the client at project meetings.	Project Meetings
Lean Practitioner	Responsible for the identification of areas for development and improvement across the Highways Sector at Company A. Usually, the lean practitioners are the professionals who chair the meetings, as a neutral facilitator.	Interview, Project Meetings
Lean Manager	Responsible for managing the continuous improvement in the company and projects, which seeks to optimize the design process, through incremental changes in processes in order to improve efficiency and quality.	Meeting, Project Meetings
Joint Venture Company representative	Representative of Joint Venture Companies.	Project Meeting
Contractor representative	Representative of the Contractor Company.	Project Meeting

Observation - Responsible: Carries out the work to complete the task, makes decisions. **|** Accountable: Ensures work is complete and is the last one to review the task before it's deemed complete.

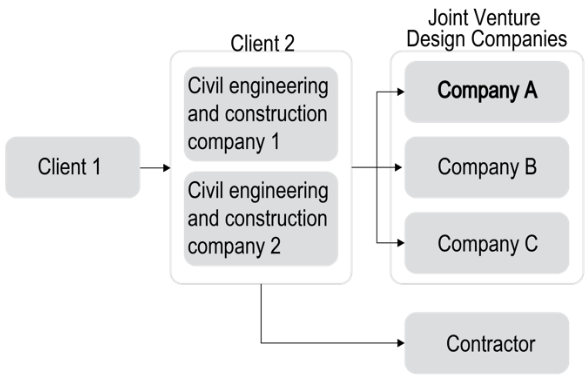
Source: Company A.

4.3.2.1 Embedded Empirical Study 1 (EES1)

Embedded Empirical Study 1, i.e. Project A, was part of the construction of a new railway that will support congested existing rail lines. The trains on the new line will serve over 25 stations connecting around 30 million people. Company A was responsible for the design of 80 km of a project with around 530 km of the full network. The design development was divided into small segments of 10 kilometres. Each of these segments was developed concurrently by sub-disciplines (e.g. highways team 1 and 2), aiming the delivery of the design according to procurement and construction dates on time. This research study was limited to the design of one sector of 10 kilometres.

The main project stakeholders are schematically represented in Figure 27. There were two client organisations: (i) client 1 was an executive non-departmental public body, in charge of developing and promoting the UK's new high-speed rail network; (ii) client 2 was a joint venture between the two large civil engineering and construction companies. Since it is a large project, the design was undertaken by a joint venture between three design companies, company A, B and C. This investigation considered the perspective of the company A.

Figure 27 – EES1: stakeholders.



Source: the author.

The project was divided into five design stages: (i) parliamentary design, which provides detail to develop construction methodology, evaluate environmental impacts, and prepare estimation of expenses; (ii) specification design, for design and construction contracts; (iii) employer requirements design, related to the definition of the scope for construction contracts; (iv) scheme design, to obtain approvals and permissions to construct; and (v) detailed design, for manufacturing and construction. During data collection, the project was moving from schematic to detail design.

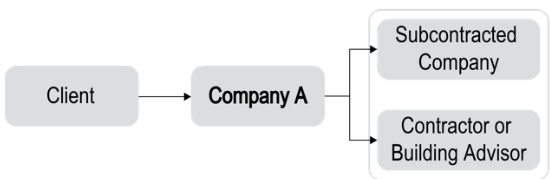
4.3.2.1 Embedded Empirical Study 2 (EES2)

Embedded Empirical Study 2, i.e. Project B, was a national and regional strategic link for a range of traffic movements for east-west journeys in the North of England with the aim of provide connections for freight and businesses in the regions. The existing highway carries high levels of traffic and it is also an important tourism route. Design investigations were underway to examine the option of duelling the road and making other improvements along its length in order to support future local and national growth and development.

The project development was divided into seven design stages defined by the client as a standard: (i) stage 0, a strategic level of development; (ii) stage 1 is related to the options identification for public consultation; (iii) stage 2 is defined as options selection, in which recommendations for preferred route announcement (PRA) were made; (iv) stage 3 is the preliminary design; (v) stage 4 relates to statutory procedures and power; (vi) stage 5 is concerned with construction preparation; (vii) stage 6 consists of construction commissioning and handover, i.e. the road opens at the end of this stage; (viii) stage 7 is closeout. Those stages were organised into three phases: options (phases 1 and 2), development (phases 3, 4 and 5), and construction (phases 6 and 7).

It was in the options phase (phase 2) when data was collected. The design developed at that phase supported the decision about which option to take forward (Preferred Route Announcement - PRA), also considering the technical review and the business case. Company A was in charge of managing the design process, and has direct contact with all stakeholders involved, i.e. the client organisation, a subcontracted company and a building advisor (Figure 28). There was daily contact with the client and quarterly contact with other stakeholders. The building advisor company provided support in construction definitions and in choosing cost-effective options during the options phase (stages 1 and 2). The building advisor should be replaced by the contractor in the development phase. The company also has a sub-contracted company, which was supporting and providing traffic data analysis.

Figure 28 – EES2: stakeholders.



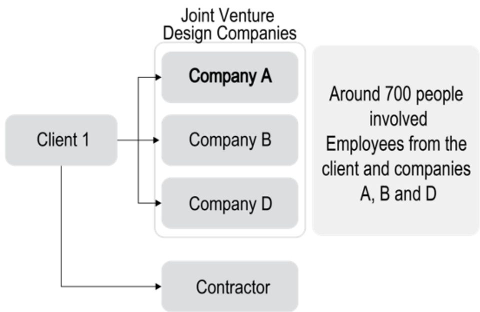
Source: the author.

4.3.2.2 Embedded Empirical Study 3 (EES3)

Embedded Empirical Study 3, i.e. Project C, was a complex highways infrastructure project in East London. The project included design development for the main government organisation responsible for the highways network in England, connecting the North to South of London through a tunnel under a river, with 20 km of roads connecting it. The project followed the same design stages as project B (embedded empirical study 2), considering that it was the same client. It was at the preliminary design phase when data was collected and analysed, in which the options selected at the previous phase were revisited and refined. It was necessary to consider the requirements from different stakeholders and disciplines at this phase, and to coordinate the interdependent decisions and interfaces.

The design was carried out by a joint venture of three companies, which are titled in this report as Company A, B and D (Figure 29). The preliminary design phase involved around 700 people, including employees from the client and the design companies. This investigation considered the perspective of the company A.

Figure 29 – EES3: stakeholders.



Source: the author.

This project had a Lean Strategy and Deployment Plan, defining continuous improvement requirements and competencies. The lean implementation was focused on (i) the Last Planner System concepts; (ii) choosing by advantages (CBA), (iii) visual management, and (iv) a Lean training program and development, as described by Christensen et al. (2020), who also developed a research study in Project C. The implementation has been supported by lean managers. The decision-making considered CBA approaches, integrated with the Last Planner System, as described by Schöttle et al. (2020).

The design was developed in a structured way, considering all relevant interfaces in design decision-making points, enabling cross-disciplinary involvement. This empirical study was focused on design planning and control only due to the limited time to develop the case study.

4.4 RESEARCH PROCESS AND SOURCE OF EVIDENCES

This research study adopted multiple sources of evidence, allowing the data triangulation as a strategy for generating more reliable results, increasing the validity of the research findings, as described by Mathison (1988). The triangulation by multiple sources of evidence enables a solid and stronger substantiation for the solution and hypotheses (EISENHARDT, 1989). Yin (2003) suggested that the following sources of evidence can be used: interviews, records of archives, analysis of documentation, direct observations, participant-observation and analysis of physical artefacts.

Triangulation was done considering the perception of (i) the users, who directly or indirectly used the VM tools; (ii) the researcher, in her role as participant observer; and (iii) other academic researchers and experts from both academia and industry, who had experience in this topic. The users from both studies refer to project managers, team members, and client. The users in the Exploratory Study were defined as coordinators and project managers, client/end-user, designers, interns and other professionals related to the design development team. The users from the Empirical Study were described as project managers, directors, BIM and GIS managers, team leaders and members, Lean managers and practitioners, client, contractor, subcontracted companies. Both studies considered users from different hierarchical levels of the design process.

4.4.1 Phase 1: Overall understanding and Exploratory Study

The data collection and analysis can be divided into two sections: (i) understanding of the overall problem; and (ii) data from the exploratory study.

4.4.1.1 Understanding the overall problem

The overall understanding of the problem and context was initially obtained through participant observation in meetings and workshops with specialists in the area, both from academia and industry. Some of them had knowledge on relevant topics, such as VM, requirements management, use of digital tools in the design process, project management, among others, as shown in Figure 30.

The meetings typically followed the subsequent structure: after a brief explanation of the research study topic, questions emerged along with the explanation of the specialists, supporting in a greater understanding of the VM practices and digital technologies integration. The questions were related to the information needed in each type of VM tools, looking for what, where, how, when questions, guided by the following structure: (i) identifying the information required for each process; (ii) analysing where the information is found by its users; (iii) understanding transfer, deliver, adoption and selection of information; (iv) identifying when the information is required by other disciplines or organisational levels. The sources of evidence 1, 2 and 3 provided a general and broad understanding of the VM problem.

The workshops were characterised by presentation and collaborative discussion with the attendees. The data collected through the events 4 and 5 provided an overall understanding of the construction and design context. Theoretical contributions emerged at early stages of the research, through the analysis of data collected from these initial meetings and workshops, as well as the theoretical basis from the literature review.

Figure 30 – Phase 1– Understanding the overall problem - Source of evidence: meetings and workshops

ID	Source of Evidence	Dur.	Attendees	Description	Understanding	
					Problem	Context
1	Meeting	60 min	1 Architect w/ experience in Lean construction 1 BIM Manager	General discussion about VM and digitalisation in the design-production interface, and identification of improvement opportunities	x	
2	Meeting	60 min	1 Civil Engineer professional 1 Architect, both w/ experience in Project Management and BIM	General discussion about VM and digitalisation in project management, and identification of improvement opportunities	x	
3	Workshop	30 min	1 Professor and researcher w/ experience in VM in project	General understanding of the problem	x	
4	Workshop	180 min	1 Professor and researcher w/ experience in VM Ph.D. students	Discussion of constructs	x	x
5	Workshop	90 min	1 Professor and researcher w/ experience in VM 1 Professor w/ experience in digital technologies for design M.Sc. and Ph.D. students	General discussion of VM constructs	x	x

Source: the author.

4.4.1.2 Exploratory study

The involvement of the researcher in this project allowed participant and direct observation in project meetings at different organisational levels and document and VM tools analysis. The different sources of evidence enabled insights related to the adoption of analogue and digital VM tools to support design processes. From a practical point of view, a need to better manage the design processes and the transfer of information between all stakeholders was identified at the beginning of the process.

The participant observation is classified in four different types of project meetings, i.e. project meetings (between disciplines), internal meetings (design team and requirements management team), project team meetings with client, and meetings with client for design assessment.

Collaborative practices between the design teams were analysed through participation in internal meetings between the design team and requirements management team, project meetings with all design disciplines, and meetings with the client (Figure 31). It was also possible to identify how the information was transferred between teams at an operational level, through participant observation of the day-to-day design and management processes, including daily catch-up meetings. Among the main activities and contributions, there was an understanding of the context, analysis of existing practices (analogue and digital visual tools), identification and reflection of potential uses of a hybrid approach to support visual management in design. This process was iterative, as the theoretical contributions emerged and were refined as soon as new insights emerged from data collected and insights from existing literature. The results found in the exploratory study were constantly compared and evaluated with the existing literature on the topic.

Figure 32 presents the documentation analysed in the exploratory study, which considered the qualitative analysis of VM tools for design planning and control, VM tools for design coordination and planning and control documents.

Figure 31 – Phase 1– Exploratory Study – Source of evidence: participant observation.

ID	Source of Evidence	Dur.	Teams involved	Activities' Description	Number of attendances
1	Participant-observation	120 min	All disciplines	Project meeting 1 - Design development and coordination meeting	**1**
2	Participant-observation	420 min	All disciplines	Project meeting 2 -General planning meeting	**4**
3	Participant-observation	150 min	All disciplines	Project meeting 3 - Weekly planning and control meeting	**2**
4	Participant-observation	480	Architectural design team and requirements management team	Internal meeting 1 - Design development and coordination meeting	**2**
5	Participant-observation	240	Architectural design team and requirements management team	Internal meeting 2 - General planning meeting	**2**
6	Participant-observation	330 min	Architectural design team and requirements management team	Internal meeting 3 - Weekly planning and control meeting	**4**
7	Participant-observation	240 min	All disciplines and client	Project meeting with client - Design development meeting (client requirements identification, design development discussion)	**2**
8	Participant-observation	540 min	Architectural design team and client	Meeting with client for design assessment 1 - Design development meeting (conceptual design assessment with visualisation through BIM model)	**2**
9	Participant-observation	240 min	Architectural design team, requirements management team, building quantity survey team and client	Meeting with client for design assessment 2 - Design development meeting	**2**
10	Open interview	90 min	Architects involved in the design development	General evaluation of the solution	**-**

Source: the author.

Figure 32 – Phase 1– Exploratory Study – Source of evidence: documentation analysis

ID	Source of evidence	Description	Aim of the document analysis
1	VM tools analysis (qualitative analysis)	Visual tools supporting design planning and control	Basic understanding of the VM implementation in the design process
2	VM tools analysis (qualitative analysis)	Visual tools supporting design development and coordination	Basic understanding of the VM implementation in the design process
3	Document analysis (qualitative analysis)	Planning and control documentation	Basic understanding of the design management process

Source: the author.

4.4.2 Phase 2: Empirical Study

The sources of evidence in phase 2 were: (i) participant and direct observations of project meetings, (ii) open and semi-structured interviews, (iii) meetings, (iv) document from design planning and control, and VM tools analysis, (v) internal and external evaluation with experts and key members. During this phase, the investigation was guided by 'how' research questions, with the aim to better understand how the visual tools supported the design processes, focusing on digital technologies.

Interviews, direct and participant observations of project meetings, and document analysis allowed the identification of tools implemented to support different organisational levels of design management. Existing management activities were classified according to: the type of meeting (face-to-face or virtual), stakeholders involved, the frequency and duration and the aim. The integration of VM tools were also analysed within those collaborative management processes. During the whole empirical study, different analogue and digital tools were analysed, supporting the identification of (i) how the information is transferred, (ii) what information is needed, (iii) by whom it is needed and (iv) when it is necessary. The researcher also analysed issues related to the effectiveness of VM implementation, considering the main benefits and barriers.

All semi-structured interviews adopted an interview protocol (see appendix A), which were recorded and most relevant were also transcribed. The transcriptions were non-verbatim, capturing the fundamental meaning behind the interviews, also rectifying the errors in grammar and removing words and songs that did not contribute to the underlying message. Key insights and interviewers' notes were incorporated into a database straightaway after each interview. An examination of the transcriptions was carried out to identify key constructs and their connections, also contributing to the identification of main challenges and opportunities to improve within the design process. The data analysis was done through a qualitative approach to identify key constructs and requirements from each interview.

The identification of the real problem of VM and digitalisation in the design process at company A was supported by the following source of evidence (Figure 33).

Figure 33 – Phase 2 – General understanding of context and problem - Source of evidence: interviews, meetings, workshops.

ID	Source of evidence	Dur.	Approach	Participants	Description
1	Meeting	60 min	Face-to-face	1 Associate Technical Director 1 Highways Sector BIM Manager	Presentation of Research Plan and understanding of empirical study context
2	Meeting	20 min	Virtual Call	2 Associates Technical Directors	Definition and understanding of empirical study context (civil engineering projects)
3	Open Interview	45 min	Face-to-face	1 Project Manager	Understanding of company context and design management process
4	Open Interview	60 min	Face-to-face	1 Senior Consultant	Identification of digital visual tools adopted, understanding of information transfer between stakeholders, and understanding of tools' devising
5	Open Interview	60 min	Face-to-face	1 Sector BIM Manager	General understanding of BIM process and design coordination
6	Semi-structured interview	60 min	Face-to-face	1 Associate Technical Director	Identification of Lean processes and practices adopted at the company
7	Meeting	120 min	Face-to-face	Company team, External Company team and Client Lean team	Identification of good practices in design management with other company from the civil engineering sector (benchmarking)
8	Open Interview	25 min	Face-to-face	1 team member (CAD technician)	Discussion related to the digital tools adopted
9	Workshop	120 min	Face-to-face	2 Associates Technical Directors and 01 Senior Technical Director	Discussion about design management processes
10	Workshop	240 min	Face-to-face	2 Associates Technical Directors	Discussion about design management process and general visual management practices
11	Open Interview	45 min	Face-to-face	1 Associate Technical Director	Identification and evaluation of design management processes and Lean strategies adopted
12	Meeting	15 min	Virtual Call	1 Business Director 1 Associate Technical Director	General understanding about the context and evaluation of constructs
13	Semi-structured interview	25 min	Virtual Call	1 Senior consultant (GIS specialist)	Discussion about design coordination tools

Source: the author.

4.4.2.1 Embedded Empirical Study 1 (EES1)

The sources of evidence were described through (i) semi-structured interview (Figure 34), (ii) attendance to planning and coordination project meetings (Figure 34), and (iii) documentation analysis (Figure 35). The semi-structured interview with the Project Information Manager (Figure 34) provided an understanding of digital design workflows and how the information is transferred within the disciplines.

Figure 34 – Phase 2 – EES1 – Main source of evidence.

ID	Source of evidence	Dur.	Approach	Participants	Description	Number of attendances
1	Participant-observation	390min	Face-to-face	1 Project Manager, 2 Subcontracted Company leaders (drainage, embankment, landscape), 2 Contractors, 1 Client, 1 Advisor, 1 BIM Manager, 6 Team Leaders and Members (1 Structure team lead, 2 Highways/ Highways drainage team lead and member, 1 Culvert team lead, 1 Landscape team lead, 1 Geotech team lead).	Collaborative Planning Session (project meeting 3)	**1**
2	Open Interview	60 min	Face-to-face	1 Project Information Manager	Understanding the BIM process	**-**
3	Participant-observation	360min	Face-to-face/Virtual Call	12 Team Leaders, 1 Project Manager, 2 Directors.	Design coordination meeting (project meeting 9)	**2**

Source: the author.

The attendance to some project meetings (Figure 34) supported the initial mapping of collaborative practices, i.e. management activities, and visual management tools implemented to support those meetings, considering both analogue and digital VM implemented. The data collected in this embedded empirical study supported the understanding of the design process context. However, a second round of data collection and analysis was carried out by the researcher, aiming to analyse the design coordination meetings, as this project was in the detail design phase and required a greater implementation of design coordination VM tools.

The analysis of VM tools and design planning documents supported the initial understanding of the VM systems and design activities, emphasising the planning activities (Figure 35).

Figure 35 – Phase 2 – EES1 – Source of evidence: documentation analysis.

ID	Source of evidence	Description	Aim of the document analysis
1	VM tools analysis (qualitative analysis)	Design planning and control VM tools: - Collaborative planning board with milestones and deliverables - Whiteboards - assumptions and key actions - Whiteboards - risks and opportunities	Basic understanding of the VM system and planning and control system
2	VM tools analysis (qualitative analysis)	Design coordination VM tools: - Navisworks for clash detection, quality control and control of changes	Basic understanding of the VM system and coordination activities
3	Document analysis (qualitative analysis)	Planning and control documentation	Identification of good practices and opportunities to improve in the planning system

Source: the author.

4.4.2.2 Embedded Empirical Study 2 (EES2)

The sources of evidence were described as (i) open and semi-structured interviews (Figure 36), (ii) direct and participant observation of project meetings, such as planning and coordination project meetings (Figure 36), and (iii) documentation analysis, e.g. analysis of VM tools interfaces and written reports (Figure 37).

The open and semi-structured interviews (Figure 36) supported an understanding of the complexity related to the design management processes of civil engineering projects, identifying the main stakeholders involved, overarching design management activities, and interdependency of design decisions. The data collected allowed the mapping of design management activities and VM tools adopted in project B, highlighting the organisational and technological complexity. The data initially collected from interviews was crossed with direct observations and document analysis of project meetings (Figure 36, and Figure 37), improving the information consistency besides assessing the information analysed from interviews.

Initially, the analysis was focused on design management from a broad perspective, however, interview 6 with the project manager from project B (Figure 36) and direct observations of project meetings 4 and 5 (Figure 36), emphasised the need to focus on design planning and control activities, and coordination activities. Thus, this research study limited the analysis of visual management tools to that perspective and parcel of design management.

Different types of meetings were carried out regularly, some for design planning and control and others for design coordination (Figure 36). The planning and control process included different hierarchical levels, identified during participant and direct observations of the project meeting, and refined through open interviews with the project manager, directors and team leaders and members. The design coordination meetings were identified through interviews, but the researcher was not able to attend the meeting, as the project B was at early stages of the design process (option phase). However, the identification of this type of managerial activity through interviews allowed a new cycle of data collection and analysis within project A, which was at detail design during the data collection period.

Figure 36 – Phase 2 – EES2 – Main source of evidence.

ID	Source of evidence	Dur.	Approach	Participants	Description	Num. of attend.
1	Open Interview	45 min	Face-to-face	1 Senior Consultant	Understanding of the project B and design management process	**-**
2	Direct observation	30 min	Virtual Call	1 Senior Consultant (Digital Tools Developer) 1 Performance Manager Associate Director	Development of tools and continuous improvement meeting	**1**
3	Semi-structured interview	30 min	Face-to-face	1 Deputy Customer Manager	Understanding of design management activities and its interface with stakeholders' team	**-**
4	Direct observation	300m in	Virtual Call	1 Project Manager, 1 Technical Director, Team Leaders	Weekly Progress Meeting (project meeting 7)	**5**
5	Direct observation	90 min	Virtual Call	1 Project Manager, 1 Technical Director, Team Leaders	Lean Call (project meeting 8)	**3**
6	Open Interview	50 min	Face-to-face	1 Project Manager	Discussion about design management process and VM tools adopted at	**-**
7	Semi-structured interview	45 min	Face-to-face	1 Technical Consultant	Discussion and evaluation about the design process, design management activities and VM tools	**-**
8	Workshop	60 min	Face-to-face	1 Associate Technical Director 1 Professor w/ experience in Lean Construction	Presentation of Technical Report and partial evaluation of results (constructs, concept map, guidelines)	**-**
9	Participant-observation	360 min	Face-to-face	Project B team	Collaborative Planning Meeting (project meeting 3)	**1**
10	Participant-observation	75 min	Virtual Call	1 Project Manager, 1 Practitioner of Risk Manager, 1 Technical Director/Senior Project Manager, 1 Team Lead.	Monthly Risk Review Meeting (Project Management and Traffic) (project meeting 5)	**2**
11	Participant-observation	45 min	Face-to-face/Virtual Call	1 Project Manager, 1 Technical Director, Team Leaders	Stand up Weekly Progress Meeting (project meeting 7)	**1**
12	Open Interview	60 min	Virtual Call	1 Technical Director/Principal design manager	Discussion about design coordination tools	**-**
13	Participant-observation	60 min	Face-to-face/Virtual Call	1 Project Manager, 1 Client Representative, 2 Technical Directors, 1 Project Director, 1 Risk Manager, Team Leaders	Monthly Progress Meeting (project meeting 4)	**1**
14	Open interview	90 min	Face-to-face	2 Associates Technical Directors	Artefact partial evaluation of results (constructs, concept map, guidelines)	**-**
15	Semi-structured interview	45 min	Virtual Call	1 Technical Director	Analysis of VM tools for design coordination, planning and control	**-**
16	Semi-structured interview	30 min	Virtual Call	1 Risk Manager	Discussion about VM tool for planning and control	**-**

Source: the author.

The contributions were evaluated mainly in two events carried out at Company A, presented in Figure 36. The first event was a workshop in which the results of this investigation were presented and evaluated, based on a Technical Report, in which the initial guidelines, concept map, and constructs were described (workshop 8). The workshop also addressed the discussion on the model for integrated design management and VM tools. The second event was an open interview with two directors involved in the Lean improvement processes within the company A (interview 14). Evaluation 1 was performed in December of 2019 and evaluation 2, in January of 2020. The solution was evaluated considering some criteria presented in section 4.2, which will support the final evaluation through the constructs of utility and applicability (see section 4.5).

The analysis of VM tools interfaces (see description on Figure 37) was divided into: (i) design planning and control tools, and (ii) design coordination tools. VM tools were used to support design planning, control and coordination at tactical and operational levels, see more information on chapter 5. The analysis of design planning documents also supported the understanding of the level of information needed at different organisational levels. Such analysis of documents also helped in the identification of good practices and opportunities to improve related to Last Planner implementation at the company.

Figure 37 – Phase 2 – EES2 – Source of evidence: documentation analysis.

ID	Source of evidence	Description	Aim of the document analysis
1	VM tools analysis (qualitative analysis)	Design planning and control VM tools: - Collaborative planning board with milestones and deliverables - Whiteboards - assumptions and key actions - Whiteboards - risks and opportunities - Performance Dashboard 1 (PowerBi) - Activity tracker (PowerApp)	Understanding of the VM system supporting planning and control system Identify specific detail of the VM tools
2	VM tools analysis (qualitative analysis)	Design coordination VM tools: - Navisworks for clash detection, quality control and control of changes - GIS for coordination	Understanding of the VM system supporting coordination activities Identify specific detail of the VM tools
3	Document analysis (qualitative analysis)	Planning and control documentation	Identification of good practices and opportunities to improve in the planning system
4	Document analysis (qualitative analysis)	BEP (BIM execution plan) analysis	General understanding of design workflows
5	Document analysis (qualitative analysis)	Written reports about the implementation of tools and process, internal emails, published information about the company on the internet	Understanding of the VM system and design process
6	Document analysis (qualitative analysis)	Published information about the company on the internet	Understanding of the VM system and design process

Source: the author.

4.4.2.3 Embedded Empirical Study 3 (EES3)

The data collection included: (i) open interviews and meetings (Figure 38), (ii) direct observation of planning project meetings (Figure 38), and (iii) VM and document analysis (Figure 39). Meetings and open interviews encouraged discussions about VM tools and digitalisation in design planning and control, and the researcher was able to analyse the transition process from a traditional to a digital design environment, whereas the direct observation of meetings allowed the analysis of the implementation of the digital tools in different types of meetings. Data collected in this project also supported the evaluation of the contributions and results achieved so far. Interviews and meetings, direct observations of project meetings, and document analysis, i.e. photographic records of the traditional big room implemented in the office based in London (Figure 39) also provided an understanding about the lean approaches implemented in the project, such as Big Room, Last Planner and CBA.

Figure 38 – Phase 2 – EES3 – Main source of evidence.

ID	Source of evidence	Dur.	Approach	Participants	Description	Num. of attendances
1	Meeting	15 min	Virtual Call	Business Director 1 Associate Technical Director	General understanding of the project	-
2	Meeting	90 min	Virtual Call	1 Associate Technical Director 1 Lean Manager	Discussion and evaluation of Visual Management, considering analogue and digital tools - discussion of new approaches and constructs, focusing in the analysis of hybrid approaches	-
3	Meeting	90 min	Virtual Call	1 Associate Technical Director 2 Lean Managers	Discussion and evaluation of Visual Management tools and design management processes, digitalisation - discussion of new approaches and constructs, focusing in the analysis of hybrid approaches - evaluation of visual management and design management practices in the project C	-
4	Direct observation	45 min	Virtual Call	2 Project Manager (Development Phase and DCO Application) 1 Lean Manager (Facilitator) 17 Team Leaders and Members	Weekly Progress Meeting (project meeting 7)	1
5	Direct observation	45 min	Virtual Call	2 Project Manager (Development Phase and DCO Application), 1 Risk Manager, 1 Lean Manager (Facilitator) 6 Team Leaders and Members	Management Performance Review Meeting (project meeting 13)	1
6	Open interview	45 min	Virtual Call	1 Lean Manager	General understanding of VM tools and design management processes	-
7	Open interview	60 min	Virtual Call	1 Lean Manager	General understanding of VM tools and design management processes	-

Source: the author.

The analysis of VM tools interfaces within design planning and control (Figure 39) was divided into analogue and digital VM tools. The photographic record analysis provided an understanding of the analogue VM tools developed and implemented in a traditional big room, since the researcher was not able to visit the office due to the pandemic situation. The analysis of design planning documents also supported the understanding of the level of information needed at different organisational levels, as well as the identification of good practices in the implementation of Last Planner (e.g. production calls and performance review meetings).

Figure 39 – Phase 2 – EES3 – Source of evidence: documentation analysis.

ID	Source of evidence	Description	Aim of the document analysis
1	VM tools analysis (qualitative analysis)	Analogue VM tools for design planning and control: - Project milestones board - 4 weeks lookahead board - Activities completed board - Reasons for non-completion board - Control board - Action board (3C's and Risk)	Basic understanding of the VM system and planning and control system Understand the implementation of analogue VM tools and big room
2	VM tools analysis (qualitative analysis)	Digital VM tools for design planning and control: - Activity tracker with weekly lookahead (BIM 360 Plan) - Performance Dashboards 2	Basic understanding of the VM system and planning and control system Understanding the impact of changes to a digital VM system
2	VM tools analysis (qualitative analysis)	Digital VM tools for continuous improvement: - Project overview board - Look after people, success, news board - Evolve board (improvement ideas and lessons learnt)	-
3	Document analysis (qualitative analysis)	Planning documents	Understanding of planning and control system
4	Photographic records analysis qualitative analysis)	VM room supporting the collaborative planning	Understanding of analogue VM system

Source: the author.

4.5 EVALUATION OF THE SOLUTION

Design science research consists of creating things that operate for human purposes, and, it should be evaluated against utility or value criteria considering a community of users (MARCH; SMITH, 1995), thus, it implies an attempt to explicitly demonstrate the utility and practical applicability of the solution (KASANEN; LUKKA; SIITONEN, 1993; MARCH; SMITH, 1995). March and Smith (1995) highlight the importance of the artefact evaluation to analyse the results of the process, understanding its performance and progress comparing with existing solutions. Thus, the constructs of utility and applicability are considered in this research study ().

This investigation considered external and internal validity, as described by Van Aken (2004). The key sources of evidence related to the final reflection and refinement of the artefact are described as internal and external evaluations: (i) researcher's perception; (i) workshops and presentations, enabling discussions and presentations with key stakeholders from the studies, as well as international professors and external members; (iii) open interviews and meetings developed with key member of the company. The workshops and interview are described in detail in Figure 40. These sources of evidence were additional to those already presented in the sections referring to embedded empirical studies.

Figure 40 – Source of evidence: final evaluation of the artefact

ID	Dur.	Source of evidence	Participants	Description
1	30 min	Workshop	International professors and PhD students from United Kingdom and United States of America. -1 renowned construction performance developer, who was involved in the creation of the Last Planner System.	Presentation and discussion about the artefact (concept map and constructs) with experts in the topics
2	30 min	Workshop	International professors and PhD students from UK, Brazil, New Zealand and Israel. - 1 professor and specialist on the synergies of BIM and Lean Construction - 1 professor and specialist in automated code compliance checking system for the construction industry - 1 associate professor with experience in construction management - 1 professor and specialist in production management, with an emphasis on production planning and costs and in the management of the design process	Presentation and discussion about the artefact (concept map and constructs) with experts in the topics
3	60 min	Workshop	- 2 Associate Technical Directors - 1 Director	Report the diagnosis and improvement opportunities proposed; Evaluation of visual management and design management practices in the company; Benefits and implementation analysis of propositions according: pain, gain, easy to delivery, priority
4	60 min	Open interview	- 1 Associate Technical Director	Report the diagnosis and improvement opportunities proposed; General discussion and evaluation of the artefact; Evaluation of visual management and design management practices in the company
5	60 min	Workshop	- 2 Associate Technical Directors	Report the diagnosis and improvement opportunities proposed; Evaluation of visual management and design management practices in the company

Source: the author.

It is important to highlight that the solution was not properly implemented to a real situation as it emerged during the research study. Due to time constraints, it was not possible to implement and evaluate the final version of the solution.

5 RESULTS

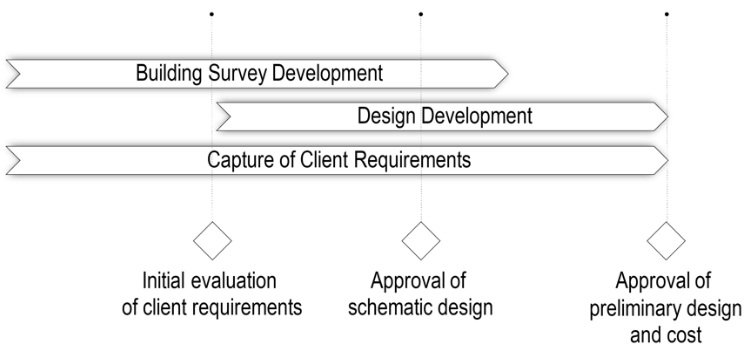
This chapter is divided into two main sections. Section 5.1 is related to phase 1, understanding the overall problem and exploratory study. Section 5.2 describes phase 2, which is associated with the main empirical study. The first section enables a general understanding of visual management and design process, describing the design development, management systems and visual tools in the exploratory study. The second section presents the results of the empirical study developed in an infrastructure design and consultancy company, which is divided into three embedded empirical studies.

5.1 PHASE 1: OVERALL UNDERSTANDING AND EXPLORATORY STUDY

5.1.1 Description of the Design Process

The managerial process was related to the initial stages of design development and to the building survey development, considering the project analysed is a retrofit. It was mostly associated to the activities of building survey development, capture of client requirements, and design development (Figure 41). There were three key milestones in this process: (i) initial evaluation of client requirements, (ii) approval of schematic design, and (iii) approval of preliminary design and cost estimate. The involvement of client representatives started at the beginning of the project.

Figure 41 – Exploratory study: Design process.

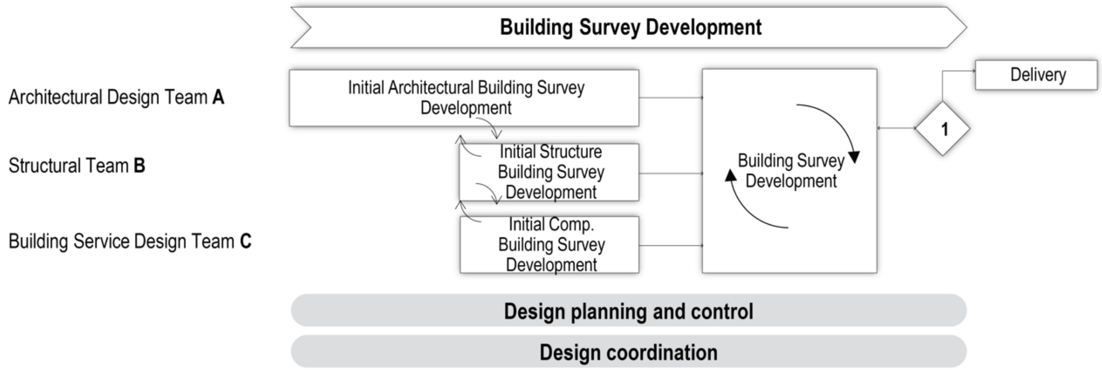


Source: the author.

Design management involved the coordination of a large design team, involving 32 people: architectural design team, structural design team, building service design team, building quantity survey team, and requirements management team.

The building survey started with the architectural design, which was the basis for structural design and building service design surveying. In these tasks there were iterative cycle among teams (Figure 42). (from an as-built model of the building was produced based on the building survey development. Design management occurred throughout the design process, considering design planning and control as well as design coordination activities.

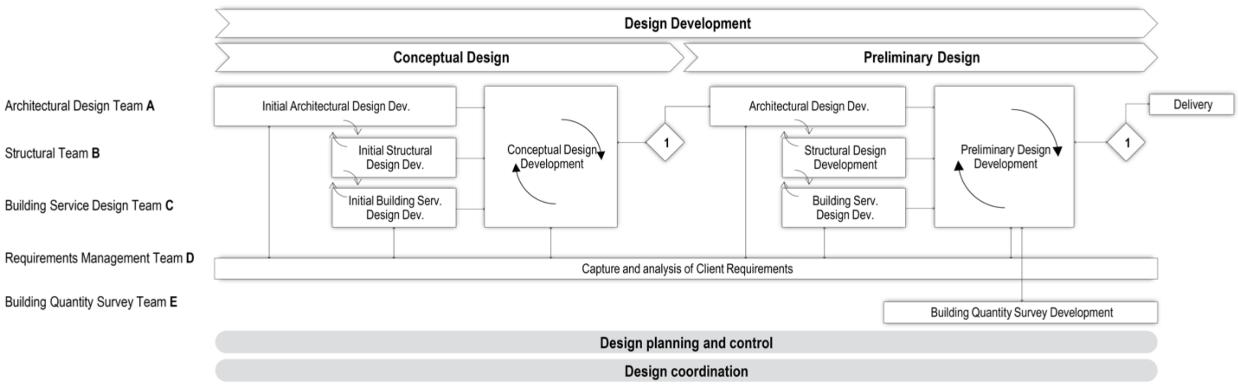
Figure 42 – Exploratory study: Building Survey Development.



Source: the author.

Design development was divided into conceptual and preliminary design (Figure 43). There were two milestones (1), which were characterised as a design review carried out by key stakeholders from the client organisation.

Figure 43 – Exploratory study: Design Development.



Source: the author.

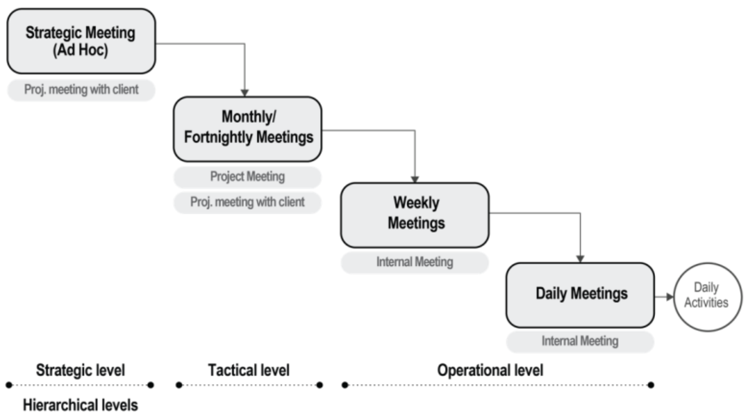
Client requirements were captured along the entire design process. It was based on visits undertaken to the existing office of the Road Federal Police, and also on interviews with representatives of different departments of the client organisation.

BIM tools were used for visualisation of the model, fast creation of multiple design alternatives, use of model data for analyses (e.g. cost analysis), maintenance of information and design model integrity, generation of drawings and documents, considering that the delivery of the preliminary design and building survey was done in BIM model and drawings.

The disciplines integration supported the decision making in all stages of design processes, increasing the activities transparency, which was enhanced by digital technological innovations. BIM models were used mostly between the architectural design and requirements management teams, to support design development and requirements modelling. The BIM models as a VM tool supported collaborative design development meetings and design coordination meetings, as joint design reviews, allowing quick and easy access to information, a better understanding of the process by client, and effective decision-making.

The design management meetings were classified by different hierarchical levels: strategic, tactical and operational (see Figure 44 and Figure 45). Strategic meetings consisted of design development meetings with the client to discuss and assess design decisions. Regarding tactical meetings, there were project meetings such as design development and coordination meetings, and general planning meetings, in which all design disciplines were involved. It was also characterised by project meeting with the client. Operational meetings were concerned with design coordination, development and short-term planning, involving the architectural design and requirements management teams only in a weekly and daily basis.

Figure 44 – Exploratory study: Types of VM tools.



Source: the author.

Figure 45 – Exploratory study: Management activities and organisational levels

	Strategic level	Tactical level	Operational
Teams involved	Design Team; Requirements Management Team; Building Quantity Survey Team; Client	Design Team; Requirements Management Team; Structure Team; Building Service Design Team; Building Quantity Survey Team; Client	Design Team; Requirements Management Team.
Reach of decisions	Between relevant stakeholders (including client)	Between relevant stakeholders of each team (and potentially the client)	Each discipline or between stakeholders of the design and requirement management team
Meetings	Project Meeting with the Client	Project Meeting between Teams (e.g. phase scheduling meeting) Project Meeting with the Client	Internal meeting within design and requirements management teams Daily meetings within design team
Frequency	Ad hoc and end of each design stage	Monthly or Fortnightly	Weekly or daily
Aim of the meeting	Design Development	Design Coordination, Design Development, General Planning	Design Coordination, Design Development, Short-term Planning

Source: the author.

Coordination and managerial activities were established in order to coordinate the work of different stakeholders and to exchange information during project meetings and internal meetings within tactical and operational levels, considering the project deadline was short and the degree of interdependency between disciplines was very high (Figure 46 and Figure 47). The daily internal project meetings followed Agile strategies, characterised as 15 minutes of a stand-up meeting between the design team (designers and interns).

Figure 46 – Exploratory study: Internal meetings within design and requirements management team.

Source: project A.

Figure 47 – Exploratory study: Project meeting between disciplines (design review).

Source: project A.

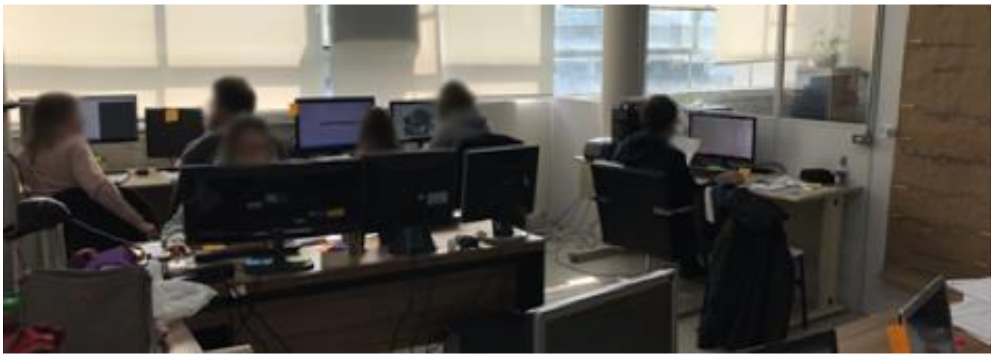
Meetings with client to assess the design milestones and decisions occurred in the design development process within in an ad hoc frequency and at the end of each stage, i.e. end of schematic design and preliminary design (Figure 48).

Figure 48 – Exploratory study: Meeting with the client.

Source: project A.

Due to the need of frequent interactions among design team members, a big room was created, in which part of the design team was co-located, and also for carrying out meetings with client representatives. The big room made it easier to promote integration and collaboration between the design teams, as it was possible to use visual tools and create opportunities for informal face-to-face communication (Figure 49).

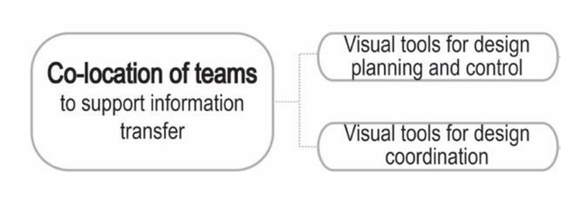
Figure 49 – Exploratory study: Adoption of Big Room



Source: project A.

Different VM tools supported those meetings, such as: (i) documents displayed on the wall (Figure 46 and Figure 47), (ii) whiteboard for discussions about design specifications (Figure 47), (iii) collaborative weekly activity tracker board considering short-term planning (Figure 51), (iv) collaborative deliverables and milestones board for phase scheduling (Figure 51), and (v) BIM model adopted as model visualisation and coordination tool (clash detection). Two main types of visual tools to support the design management were identified (Figure 50): visual tools to support design planning and control, and to support design coordination. The VM tools for planning and controlling activities were mainly analogical, e.g. collaborative activity tracker board and collaborative phase scheduling board. By contrast, design coordination was supported by a combination of analogical and digital tools, such as documents displayed at wall and BIM model visualisation. The researcher was actively involved in the development of all VM tools.

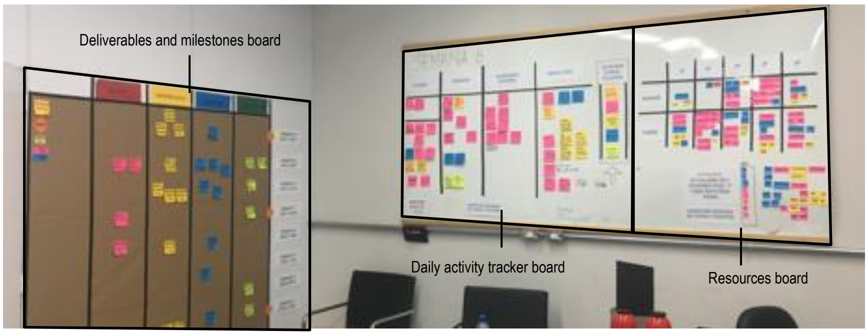
Figure 50 – Exploratory study: Types of VM tools.



Source: the author.

The analysis below considered the data collected through participant observation of project meetings, analysis of VM tools interfaces and the involvement of the researcher in the design and VM tools development, allowing a greater understanding about the use of the tool during the design management process.

Figure 51 – Exploratory study: Analogue VM tools supporting project meetings (phase scheduling) and internal meetings (short-term).



Source: project A.

- Daily activity tracker board (Figure 52): it mostly supported the communication between the architectural design team and requirements management team. The board was developed and updated by the team, and each team member was in charge of their own tasks and stickers. The actions were tracked considering three status: to do (backlog), doing and done, which follow the Kanban approach. As the building survey and design development had overlapping activities, the pink stickers were associated to the architectural design building survey activities, whereas the yellow stickers were related to the architectural design development activities. The blue stickers represented the actions related to requirements management team, and the orange stickers were related to managerial activities (e.g. updating the plan and reviewing the progress).

- Deliverables and milestones board (Figure 53): it supported the communication between all teams. The columns represent the main stages of the process, e.g. building survey, preliminary design, requirements management. Whereas the lines described the weeks and the orange diamond pointed out the key process milestones, which were described as delivery of the BIM model and drawings, or presentations to the client. This VM tool supported tactical and operational meetings within and between disciplines.
- Resources board: it supported the communication between the architectural design and requirements management teams, assigning the availability of resources for each day of the week and also visually showing when each team member would be working in the big room. It was updated by each member on a weekly basis.

Figure 52 – Exploratory study: Daily activity tracker board

Source: project A.

Figure 53 – Exploratory study: Deliverables and milestones board

Source: project A.

5.1.2 Discussion

The Lean and Agile strategies adopted aimed at a more efficient process and also an increase in the product value, considering a greater and earlier involvement of the client, collaborative work between different disciplines, and early capture of emergent requirements. The exploratory study supported the understanding of VM tools and their integration with the management activities, also supporting the understanding of how information was transferred in design development through visual tools, enabling the analysis of analogue and digital tools. VM tools were used for both process transparency (planning activities) and product transparency (3D models, for example), as defined by Klotz (2008). The main contribution of this study was associated to the understanding of the variety of VM tools supporting different design management activities, classified as design planning and control and design coordination tools.

The co-location is described by Dave, Koskela e Kiviniemi (2013) as a method to shorten the response times, also reducing rework and improving information sharing, especially related to tacit knowledge. The big room encouraged an iterative process with the design team members, as well as a collaborative process and a faster transfer of information with the other disciplines and client. The room has also become an informal meeting place for the teams (mostly for architectural design team, requirements management team and building survey team); and such management strategies were related to a common understanding among the users, enabling a solid common ground for design development, as suggested by Koskela, Tezel e Tzortzopoulos (2018).

The adoption of visual tools for design management promoted an increase in the engagement and autonomy of the users, as well as an improved decision-making process observed in the daily routine of the architectural design and requirements management team, which emphasised the importance of transparency between teams (MOSER; SANTOS, 2002). It also helped in the identification of issues regarding delay and overload of activities, supporting the analysis of reasons for overdue activities, as underestimation of time and resources.

For instance, the daily activity tracker boards supported the realization that the time required to undertake the building survey was underestimated. The adoption of visual boards also encouraged daily and quick meetings as it was needed to discuss and get feedback about ongoing activities and emerging constraints. One drawback was the traceability of information, which was done through photographic records, a manual-based process that is prone to errors. The phase scheduling board allowed a continuous visualisation of milestones, enabling the team members to be aware of the deadlines more easily. It was reviewed every month, allowing discussions around the deadlines and milestones.

BIM tools were adopted as a way to integrate different stakeholders, as also mentioned by Svalestuen and Lohne (2016). Participant observation and analysis of the BIM model implementation as a visual tool during design coordination meetings explored and emphasised some advantages already identified in the literature, such as: (i) having all information in the same place (GREIF, 1991; SACKS et al., 2010), increasing the traceability and storage of information (ii) visualisation during all process, allowing an easier understanding and decision-making by all stakeholders (SACKS; TRECKMANN; ROZENFELD, 2009; MURATA, 2018), and (iii) anticipating risks and waste due to information accuracy (MURATA, 2018).

5.2 PHASE 2: EMPIRICAL STUDY

5.2.1 Description of the Design Process of Company A

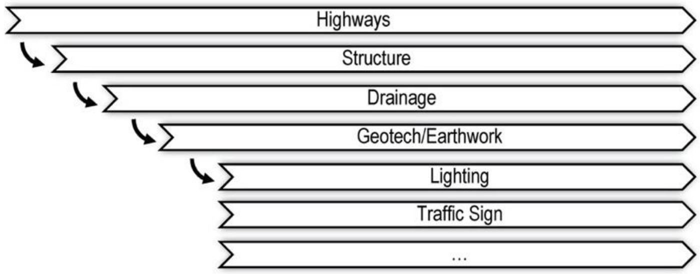
The highways design process was usually divided by Company A to overarching activities: project initiation stage, requirements definition, information management, design development, managing progress, construction stage support and lessons learnt (Figure 54), which are described by the company in 3 main stages: (i) market-to-opportunity, which is characterised as a phase where awareness is created, the needs are identified and the opportunity is created; (ii) pursuit-to-win, related to the creation of a pursuit team, offer and contract awarding; and (iii) deliver-to-results, described as project initiation stage, project planning, project execution and control and close project stage. The digital workflow followed the ISO 19650 and it was applied to all design, engineering and construction projects alongside with the procedures described before, following some steps: (i) assessment and need; (ii) invitation to tender; (iii) tender response; (iv) appointment; (v) mobilization; (vi) collaborative production of information; (vii) information model delivery; (viii) project close out. The main outputs were described by four different packages for submission: calculations, models, drawings and documents.

Figure 54 – Empirical Study: Empirical Study Design process overarching activities.

Source: adapted from Company A documents.

The design development stage is divided into 18 key design processes, according to the disciplines involved, such as: (1) Highways; (2) Drainage; (3) Structures; (4) Traffic Modelling; (5) Geotechnics; (6) Technology; (7) Pavement; and (8) Traffic Signs. The design process of highways projects at Company A tries to follow a sequence of activities and disciplines, usually starting with the highways team developing the design strategy, followed by structures, drainage, geotechnics teams, and then the other teams start their activities (Figure 55). The initial sequence is important as the results and definitions from some disciplines influence in the design of others, avoiding rework and generating more value to the process. By following the general sequence described above, the company usually tries to start the design of each discipline as soon as possible, considering the minimum information required by each discipline for specific section of the highways, since it is inefficient to run clash detection and do checks between the disciplines without all disciplines in the models. Therefore, it is important to have at least strategic definitions from all disciplines at the beginning so as to promote an overall understanding about design interdependences. After the initial sequence, there was an overlap of the design activities by all disciplines, as demonstrated in Figure 55.

Figure 55 – Empirical Study: Design process sequence of activities.



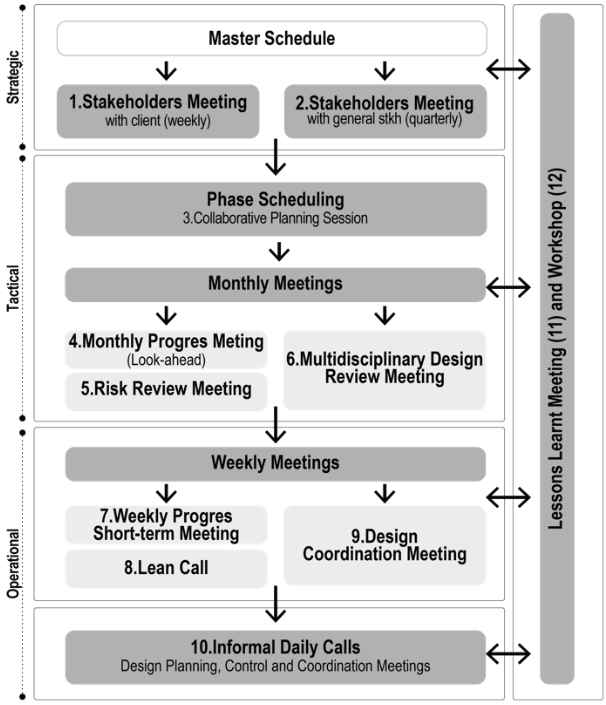
Source: the author.

According to designers, project and BIM managers interviews, most design disciplines tend to not respect the sequence and they often start the work almost at the same time, and different designs are developed concurrently. This is due to the large number of contract requirements and the short delivery time. This situation often causes rework, as teams need to work from assumptions made for other disciplines.

The starting point of the analysis was a general understanding of the design management processes. The analysis of VM tools implemented in design management considers how those tools were integrated in collaborative meetings. These meetings were concerned with both design planning and control and design coordination activities.

Figure 56 presents a schematic representation of all types of design meetings: (1) stakeholders meeting with the client, concerned with contract management, change control, discussion and design assessment by the client; (2) general stakeholders meeting, which is related to the design evaluation with local authorities and community; (3) phase scheduling, also named as collaborative planning session, used to develop collaboratively a long term plan for a project stage; (4) monthly progress meeting with 4 weeks lookahead, to identify and remove constraints; (5) risk review meeting, which involved analysing the risk of activities from each discipline; (6) multidisciplinary design review meeting, looking at design options, impacts and cost; (7) weekly progress short-term meetings, in which design activities and deliverables are coordinated; (8) lean call, supporting the control the progress with the activity tracker tool; (9) design coordination meeting, for reviewing the progress status and identifying issues; (10) daily meetings, to monitor and coordinate daily progress of actions within each discipline through informal discussions or calls; (11) lessons learnt meetings within each discipline at the end of each design stage; and (12) lessons learnt workshop at the end of each stage or project.

Figure 56 – Empirical Study: Management activities mapping.



Source: the author.

The classification of those meetings into strategic, tactical and operational was based on the stakeholders involved, the reach of decisions made in each meeting, and the level of planning (see detail classification in the Figure 57 below). The identification of the different hierarchical levels provided an understanding of the interactions of managerial practices and Visual Management tools. The frequency of meetings depends on the hierarchical planning level. Project B was the main source of evidence for this analysis, while projects A and C provided further insights.

The **strategic level** meetings involved project manager, directors, and clients. Such meetings were characterised by overarching activities and processes, enabling the definition of milestones and master schedule. Stakeholders' meetings (1 and 2) were carried out at strategic level.

The **tactical level** meetings enabled discussion and analysis of the programme, progress and elimination of constraints. Phase scheduling meetings (collaborative planning sessions - 3) were classified as tactical, and they have a high level of definitions and discussions. Such meetings involved all relevant stakeholders, i.e. the project manager, directors, client, team leaders, BIM manager, subcontracted companies or joint venture companies' representatives, and contractor representative. The monthly progress meetings (4), review risk (5) and interdisciplinary design review (6) meetings were also classified as tactical. They involve the project manager, team leaders and client.

The meetings at the **operational level** were divided into two types: between disciplines and within each discipline. The meetings between disciplines (7,8 and 9) involved team leaders, the project manager and the BIM manager; while the meetings within each discipline (10) involved the team members and leaders. These involved discussions on detailed activities and progress control.

Figure 57 – Empirical Study: Organisational levels.

	Strategic Level	**Tactical Level**	**Operational Level (within and between disciplines)**
Stakeholders involved	Project Manager; Technical and Project Directors; Client representative	Team Leaders; Project Manager; Client representative	Team Members; Team Leaders; Project Manager; BIM manager, GIS Manager
Reach of decisions	Between relevant stakeholders	Between relevant stakeholders of each discipline	Each discipline or between disciplines
Level of planning	Long-term	Medium-term	Short-term
Meetings	1.Stakeholders Meeting with client 2.Stakeholders Meeting with general stakeholders	3.Collaborative Planning Session (phase scheduling) 4.Monthly progress meeting with four weeks look-ahead 5.Risk Review Meeting 6.Multidisciplinary Design Review Meetings	7.Weekly progress short-term meetings (with diverse design disciplines) 8.Lean Call (with diverse design disciplines) 9.Design Coordination Meetings (with diverse design disciplines) 10.Daily meetings (one design discipline)

*The company also has lessons learnt meetings (11) and workshops (12), e.g. at the end of each design stage or end of the project. Those activities are not classified according to the organisational levels, as are concerned with all processes (as represented in Figure 56).

Source: the author.

The meetings are described in Figure 58 according to the activities involved. The structure of the meetings was analysed during the direct and participant observations. All meetings were characterised by different moments and stages, such as (i) planning, related to the planning and updating of design and managerial activities (ii) control, described as the monitoring and review of the progress, as well as identification of corrective actions; (iii) coordination, was described as a moment to discuss design independencies, definitions and design specification between disciplines and (iv) general discussions, characterised as discussion related to general agreements that were not directly related to any planning, control or coordination work packages (e.g. introductions, safety moment, agreements on meeting objectives, specification of desired outcomes, and definition of next steps). All meetings contain general discussions, as they are collaborative design meetings and, due to that, this activity is not considered in the Figure 58. The lessons learnt meetings and workshops were described by continuous improvement activities.

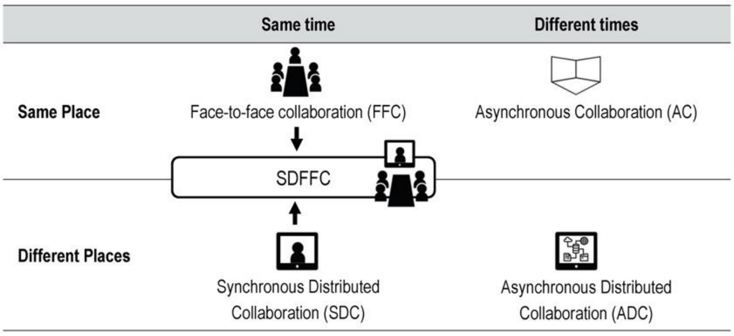
Figure 58– Empirical Study: Management activities and organisational levels.

Org. Level	Meetings (ID)	Coord.	Planning	Control	Lessons Learnt
Strategic	1.Stakeholders Meeting with client	-	x	x	-
	2.Stakeholders Meeting with general stakeholders	x	-	-	-
Tactical	3.Collaborative Planning Session (phase scheduling)	x	x	-	-
	4.Monthly Progress Meeting	-	x	x	-
	5.Monthly Risk Review Meeting	-	x	x	-
	6.Multidisciplinary Design Review Meetings	x	x	x	-
Operational (multidisciplinary)	7.Weekly Progress Meeting	-	x	x	-
	8.Lean Call	-	x	x	-
	9.Design Coordination Meetings	x	x	x'	-
Operational (inside of each discipline)	10.Daily call meetings	-	x	x	-
Improvement	11.Lessons Learnt Meeting (at the end of each stage with one design discipline)	-	-	-	x
	12.Lessons Learnt Workshop (at the end of the project with diverse design disciplines)	-	-	-	x

Source: the author.

This research project considered different approaches of communication (see further information in section 2.4), adapted from Ugwu et al. (1999) and Anumba et al. (2002), which were: (i) face-to-face collaboration (FFC); (ii) asynchronous collaboration (AC); (iii) synchronous distributed collaboration (SDC), and (iv) asynchronous distributed collaboration (ADC). The empirical study contributed to the identification of a new category, which merges two of the types described before (SDC and FFC) and can be described as: synchronous distributed and face-to-face collaboration (SDFFC). In the new category, some meetings are carried out both virtual and face-to-face, due to the fact that some team members and stakeholders were based in the same office and some in different offices, cities, or countries.

Figure 59 – Empirical Study: Collaboration approaches.



Source: the author.

Different terminologies are used to describe VM tools and Lean processes in the literature, creating a plethora of classifications for the same practice or tool. Hence, this research work focused on two types of tools, defined by the researcher as: (i) tools for design **planning and control** (type A), e.g. activity tracker and performance dashboards, and (ii) tools for **design coordination** (type B), e.g. clash detection, model visualisation, and coordination tools in general. A third type of tool, **type C**, defined as continuous improvement tools, was identified as potentially useful, such as for supporting lessons learnt activities. The VM tools identified in the empirical study are summarised in Figure 60, classified according to the types (A, B, and C) and according to the embedded empirical study in which they were identified.

Figure 60 – Empirical Study: VM tools identified.

VM type	VM Tools	EES	ID
A	Collaborative planning board with milestones and deliverables	1,2	a
	Whiteboards - assumptions and key actions	1,2	b
	Whiteboards - risks and opportunities	1	c
	Whiteboards – Deliverables	2	d
	Performance dashboards 1 (PowerBi)	2	e
	Activity tracker (PowerApp)	2	f
	Risk dashboard (balance scorecards)	2	g
	Project Milestones board (Milestones Heatmap)	3	h
	4 weeks lookahead board	3	i
	Activities completed board	3	j
	Reasons for non-completion board	3	k
	Control board	3	l
	Action board (3C's and Risk)	3	m
	Activity tracker with weekly lookahead (BIM 360 Plan)	3	n
	Performance dashboards 2	3	o
B	Navisworks for clash detection, quality control and control of changes	1,2	p
	GIS for coordination	2	q
C	Project overview board	3	r
	Look after people, success, and news board	3	s
	Evolve board (improvement ideas and lessons learnt)	3	t

*EES: Embedded Empirical Study

Source: the author

VM tools were described by using a set of classification criteria, which are presented in Figure 61.

Figure 61 – Empirical Study: VM tools classification.

VM tools classification	
1. Digitalisation Level	Digital VM tools
	Analogue VM tools
2. Communication and collaboration approaches (UGWU et al., 1999; ANUMBA et al., 2002)	Face-to-face Collaboration (FFC)
	Asynchronous Collaboration (AC)
	Synchronous Distributed Collaboration (SDC)
	Asynchronous Distributed Collaboration (ADC)
	Synchronous Distributed and Face-to-face Collaboration (SDFFC) *
3. Managerial Levels	Strategic
	Tactical
	Operational
4. Nature of VM tools	Type A (design planning and control) *
	Type B (design coordination) *
	Type C (continuous improvement) *
5. Taxonomy of VM practices in three categories of communication and integration **(BRANDALISE, 2018)**	One-to-one interactions
	One-to-many or many-to-one interactions
	Many-to-many interactions
6. Visual expression of VM tools **(BITITCI; COCCA; ATES, 2016)**	Dynamic
	Static
7. Set of VM requirements for design management within digital context (see section 3.7)	Simplicity (C1)
	Information standardisation (C2)
	Information availability (C3)
	Information accessibility (C4)
	Flexibility of tools (C5)
	Information traceability (C6)

* Suggested by the author
See appendix B for more detail about the classification and analysis

Source: the author

5.2.2 Embedded Empirical Study 1 (EES1)

Figure 62 provides details on two design management meeting types from project A identified through participant observation and interviews with team members, which are: collaborative planning session and design coordination meetings. Figure 63 presents the stakeholders usually involved in each meeting, considering internal stakeholders (project manager, directors, lean practitioner, team leaders and members and BIM manager) and external stakeholders (client, contractor, subcontracted companies/joint venture companies' representatives). The attendance of some stakeholders, such as client, contractor and joint venture company representatives, is optional. The stakeholder who chairs the meeting is also identified. In the case of design coordination meetings, meetings are chaired either by the project manager or BIM manager.

Figure 62 – EES1: Design Management Activities (meetings structure).

ID	Activity	Aim	How	Frequency/ duration	Stage	Tools
3	Collaborative Planning Session	Definition and discussion about deliverables and milestones, Development of a high-level detailed design programme	Face-to-face	Quarterly/ 6 hours	All design stages	a / b / c
9	Design Coordination Meetings	Reviewing the status of the federated model, reviewing progress, identifying issues	Shared screens with models via virtual call and face-to-face meeting	Weekly/Fortnight/ 30 min – 2 hours	From stage 2	p

Source: the author.

Figure 63 – EES1: Stakeholders involvement.

Stakeholders involved	Collaborative Planning Session	Design Coordination Meetings
Project Manager	x	z
Directors	x	x
Lean Practitioner	z	-
Team Leaders	x	x
Team Members	-	-
BIM Manager	x	z
Client	x	-
Contractor	y	-
Joint Venture Company	y	x

x – stakeholder who attends the meeting | y - optional attendance | z – stakeholder who often chairs the meeting

Source: the author.

The VM tools identified in project A are presented below (Figure 64). Some of the visual management tools were used at specific points in time and for specific activities, presenting the potential to be more broadly available and accessible to support design management. For instance, collaborative boards supporting the collaborative planning session were available only during the meeting, but could also be used to support other meetings and be available continuously to support informal meetings.

Figure 64 – EES1: tools identified.

ID	Tools	VM type	Aim	Information
a	Collaborative planning board with milestones and deliverables	A	Collaborative planning, transparency of information	Disciplines; Milestones; Deliverables by discipline; Dates (weeks)
b	Whiteboards - assumptions and key actions	A	Collaborative planning, transparency of information	Assumptions; Key Actions
c	Whiteboards - risks and opportunities	A	Collaborative planning, transparency of information	Risks; Opportunities
p	Navisworks for clash detection, quality control and control of changes	B	Clash detection, visualisation, stakeholder's engagement	Issues identified by discipline

Observation: The ProjectWise tool was used to create of a common data environment, so that information could be shared between all stakeholders involved in the project. The main functions of this tool were storing and transferring information, as well as process control, regarding design checks and reviews.

Source: the author.

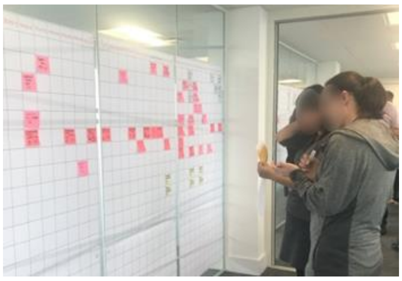
A **collaborative planning session** (project meeting 3) was undertaken along the whole design stage to develop a high-level schedule and it was reviewed every three or four months; the duration of this meeting is on average 3 hours. These sessions supported the identification and management of key constraints, agreement of the next steps to protect the baseline programme against uncertainty and agreement of the long-term plan; The meetings were focused on the agreement of deliverable dates already defined in the long-term plan (also named master schedule). The purpose of the collaborative planning meeting was to ensure that all parties understand the timeframes, their responsibilities, and consequently, the impact of not delivering their tasks. So, risks and assumptions were identified, understood and logged during the session for continuous review and management. The teams adopted two different collaborative visual boards to support the discussions and agreements. A Lean Practitioner chaired the meeting, but he had not been directly involved in the project, so his role was to bring a neutral perspective in relation to the decision making, keeping the meeting focused (Figure 68).

The collaborative planning session was divided into four main stages: (a) initial discussions, with introductions, health and safety moment[i], agreement of objectives and expected outcomes, explanation about the agenda and the dynamics, as well as definition of key project milestones and deliveries (30 minutes); (b) initial planning by each discipline, where each discipline developed a high-level programme to fit with client and procurement requirements – according to deliverables and dates already defined in the master schedule (60 minutes – see Figure 65); (c) collaborative planning, each discipline outlined their programme to the group and collectively they reviewed and improved the plan, also identifying issues or constraints, and developing actions or mitigations, as well as coordinating design disciplines (60 minutes - see Figure 66, Figure 67, Figure 68); and (d) final discussion, described as the agreement about next steps and definition about how monitoring and controlling (30 minutes). The meeting was usually very long (around 3 hours of duration), so it was difficult for attendees to keep paying attention during the whole period.

The definition and set up of principal project milestones and critical deliverables (e.g. bridges project – delivery package 1) guided the definition of deliverables for each discipline team. The deliverables from each discipline follow the name of the milestones in the stickers (illustrated in the figure – package 1 and activity 1). Some disciplines presented more than one line of activities, as they could have diverse teams working simultaneously (e.g. highways team 1 and highways team 2).

Health and Safety Moments are a brief discussion (2-5 minutes) about a specific subject at the beginning of a meeting, which can cover a variety of topics related to safety, aiming to remind employees of the importance of being safe at work and in all aspects of their lives.

Figure 65 – EES1: Planning.



Source: the author.

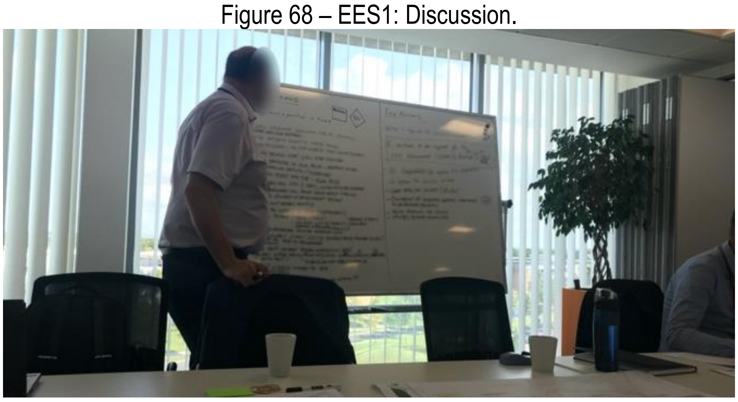
Figure 66 – EES1: Planning.

Source: the author.

Figure 67 – EES1: Coordination.

Source: the author.

Figure 68 – EES1: Discussion.



Source: the author.

The company adopted analogue VM tools (see Figure 69 Figure 70) to support decision-making and discussions at a high-level of information detail, The collaborative visual boards and whiteboards supported the development of a high-level design programme to match client priorities, identify and manage key constraints, agree next steps to protect the baseline programme and agree about the long-term plan. The collaborative board with milestones and deliverables was the main VM tool used during the meeting (Figure 69), although there were also whiteboards (Figure 70) supporting the discussions related to assumptions, key actions, risks and opportunities emerging during the meeting. The whiteboards were flexible and simple, encouraging greater engagement of the tool and ownership of the work by participants.

Figure 69 – EES1: Collaborative board with milestones and deliverables.

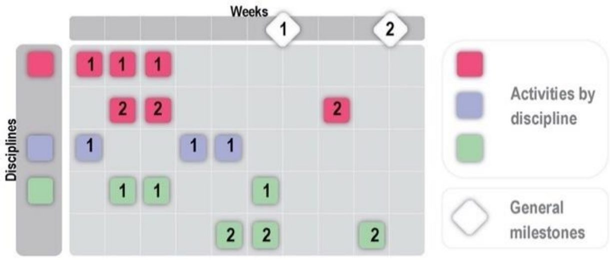
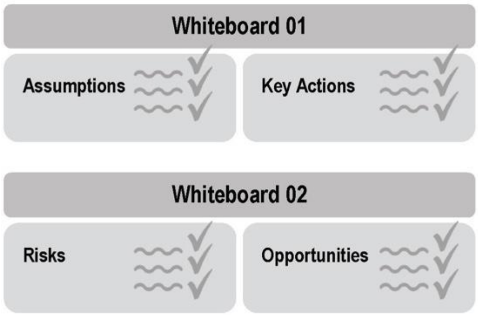


Figure 70 – EES1: Whiteboards.



Source: the author.

The project manager created the general milestones on the collaborative visual board prior to the meeting, based on the master schedule milestones (defined at the beginning of the project). The collaborative visual board with milestones and deliverables was adopted mostly in the initial planning stage (b) of the meeting, which was carried out by each team leader or representative, and during the collaborative planning stage (c), which was coordinated by the facilitator (Lean practitioner). The use of whiteboards occurred during the initial planning stage (b), enabling each team member to input information as soon as new actions, assumptions, risks and opportunities emerged. The main topics identified into the whiteboards were discussed during the last stage of the meeting, the final discussion (d), in which the following steps were agreed, as well as identifying who was responsible for each topic identified.

The main issues related to the analogues VM tools for team members were related to the difficulty in maintaining the information up to date, recording and sharing properly the information and decision-making with geographically distributed teams. There was also a lack of space to display the VM tools in company A offices, as meeting rooms were shared between different projects, limiting the availability of those tools during the meeting.

The information defined in the collaborative planning sessions was updated into the master schedule, which was produced in the software Primavera P6, also feeding and guiding the other levels of planning.

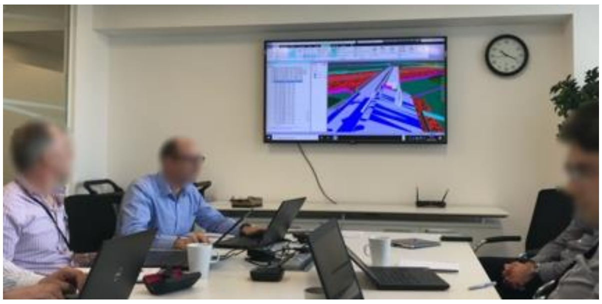
The **design coordination meeting** (project meeting 9) was identified in both projects A and B; however, the researcher was able to do participant observations in the project meeting only in the project A, due to the stage of the project (as it occurs from the preliminary design stage).

The purpose of the design coordination meeting was to review the status of the federated BIM model, including model development and clash detection, review the progress and identify issues. The meeting enabled discussions around the model quality assessment, identifying the reasons for discipline design and modelling decisions, as well as the interface discipline issues and interdependencies. It also supported collaborative decision-making points, as they reviewed design progress and identified issues collaboratively.

Two meetings were analysed in the design stage. The duration of this type of meeting may vary from 30 minutes to 2 hours, depending if they incorporate planning and control activities and depending on the design stage. The difference between the two meetings was that one of them had a planning section at the beginning of the meeting for reviewing project progress and agreed with new dates and deliverables. Both of them had informal control throughout the meeting, the project manager took notes about the decisions manually and also used a spreadsheet to support the control of actions.

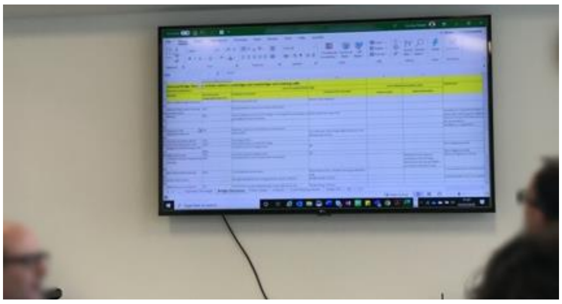
The meeting presented an irregular structure, sometimes including the planning section. The meeting analysed was very long (2 hours), and the frequency and duration of the meeting have been pointed out by interviewees as a potential waste of time, creating difficulties for attendees to be involved and focused all the time. As a consequence of the lack of a clear structure, the stakeholders did not understand their role during the meetings.

Figure 71 – EES1: Coordination (Design Review).



Source: the author.

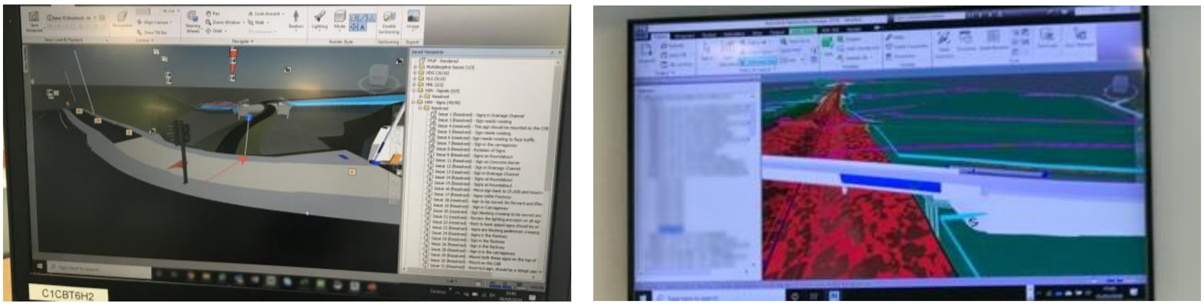
Figure 72 – EES1: Planning and Control.



Source: the author.

Figure 73 presents examples of visualizations of the federated BIM model, which was used in the identification of clashes between disciplines, and quality assurance. The combined model was adopted as a visualisation tool and drove the design decisions during the weekly or fortnightly coordination meetings.

Figure 73 – EES1: Navisworks for clash detection, quality control and control of changes.



Source: the author.

Information transfer through BIM was described as a challenge by the project information manager in the open interview. This is concerned with how the BIM model was shared and made available for all stakeholders. BIM was federated in an ad hoc way and teams worked in silos, considering that most disciplines would like to finish design batches before they share with other teams, according to the Project Information Manager perspective. The Project Information Manager and BIM manager had a central role in the integration and transfer of information in the design process. Considering the existing approach for communication and integration, the tool supported the coordination of many stakeholders and analysis of data concurrently at different moments, as observed during participant observation of coordination meetings.

The clash detection tool was used to get team members' feedback and engagement during the meetings. The visualisation of the model offers both internal and external stakeholders the opportunity to understand some design details, and create a shared understanding about the design, as identified through interviews with BIM and project information managers, as well as participant observations. The tool was adopted at some stages of the process only, such as detail design, when the design was more developed and required a high level of detail inside of the model, emphasising specific design issues that were more complex and should be discussed during the meetings.

In an open interview, the project information manager pointed out that there were barriers related to the hardship in identifying the right software at the beginning of the process, and making sure that the software chosen produce the information needed according to the client and contractor requirements. There were also issues in ensuring that the teams and stakeholders got the right information when required.

5.2.3 Embedded Empirical Study 2 (EES2)

Figure 74 presents 12 different design management meetings that were identified in project B through direct and participant observation, interviews, discussions and document analysis. Figure 75 presents the stakeholders involved in each meeting, considering both internal and external stakeholders.

Figure 74– EES2: Design Management Activities (meetings structure).

ID	Activity	Aim	How	Frequency/ duration	Stage	Tools (see Figure 76)
1	Stakeholders Weekly Meeting (w/ client)	Contract management and change control discussion	Face-to-face and/or Virtual Call	Weekly	All design stages	-
2	Stakeholders Quarterly Meeting (w/ general stakeholders)	Show and choose design options with users and community	Face-to-face	Quarterly/ 1 day	Stage 1 and 2 (Focus Group, Pre-consultation and Consultation), and at the end of each stage	-
3	Collaborative Planning Session	Definition and discussion about deliverables and milestones, develop a high-level detailed design programme	Face-to-face	Quarterly/ 6 hours	All design stages	a / b /c
4	Monthly Progress Meeting (look-ahead)	Eliminate constraints, discuss the programme, the progress, the challenges, the impediments	Face-to-face and Virtual Call	Monthly/ 1 hour	All design stages	E
5	Monthly Risk Review Meeting	Review risk of activities with each discipline	Virtual call	Monthly/ 1 hour	All design stages	G
6	Multidisciplinary Design Review Meetings	Look at design options (impacts, cost)	Face-to-face and/or Virtual Call	Ad Hoc/ 3 days	All design stages	-
7	Weekly Progress Meeting	Discussion about program; update and control of deliverables, activities, schedule of meetings and assessments.	Virtual meeting with shared screens or/and face-to-face	Weekly/ 1 hour	All design stages	-
8	Lean Call	Control of actions - Activities update (Done, Doing and Next Steps)	Virtual Call	Weekly/ 30 min	All design stages	F
9	Design Coordination Meetings	Review the status of the federated model, review progress, identify issues	Shared screens with models via virtual call and face-to-face meeting	Weekly/Fortnight/ 30 min – 2 hours	From stage 2	p / q
10	Daily meetings	Activities update (Done, Doing and Next Steps)	Virtual Call	Daily/ 30 min	All design stages	-
11	Lessons Learnt Meeting	Benchmarking between projects; discussions about main issues and lessons learnt of each project	Virtual Call	End of each stage	End of all design stages	-
12	Lessons Learnt Workshop	Lessons Learned for each project; lessons learnt review	Face-to-face and/or Virtual Call	End of the project/ 4 hours	End of the project	-

*The meetings in which the researcher did participant observation were: Collaborative Planning Session (3), Monthly Progress Meeting (4), Monthly Risk Review Meeting (5), Weekly Progress Meeting (7), Lean Call (8), and Design Coordination Meetings (9). The other meetings were identified through interviews, discussions with key team members and document analysis.

Source: the author.

Figure 75 – EES2: Stakeholders involvement.

	Meetings											
Stakeholders involved	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Project Manager	z	x	x	z	x	z	z	z	z	y	z	z
Directors	-	-	x	x	x	x	x	-	x	-	x	x
Deputy Customer Manager	-	z	-	-	-	-	-	-	-	-	-	-
Risk Manager/Practitioner	-	-	-	z	z	-	-	-	-	-	-	-
Lean Practitioner	-	-	z	-	-	-	-	-	-	-	-	-
Team Leaders	-	-	x	x	x	x	x	x	x	z'	x	x
Team Members	-	-	-	-	-	-	-	-	-	x	x	-
BIM Manager	-	x	x	-	-	-	-	-	z	-	x	-
Client	x	x	x	x	-	-	y	y	-	-	-	-
Contractor	-	-	y	-	-	-	-	-	-	-	-	-
Subcontracted Company	-	-	y	-	-	-	-	-	-	-	-	-
User/Community	-	y	-	-	-	-	-	-	-	-	-	-

x – stakeholder who attends the meeting | y - optional attendance | z – professional who chairs the meeting

Source: the author.

The VM tools identified in project B are described in Figure 76, while a short description of the meetings is presented below.

Figure 76 – EES2: tools identified.

ID	VM Tools	VM Type	Aim	Information
a	Collaborative planning board with milestones and deliverables	**A**	Collaborative planning, transparency of information	Disciplines; Milestones; Deliverables by discipline; Dates (weeks)
b	Whiteboards - assumptions and key actions	**A**	Collaborative planning, transparency of information	Objectives, Assumptions and Actions
d	Whiteboards - deliverables	**A**	Collaborative planning, transparency of information	Deliverables (surveys); Other topics (e.g. overview of the project)
e	Performance dashboard 1 (PowerBi)	**A**	Control of the projects with performance metrics	Filter by scheme/project; Weekly PPC; Reason overdue; 3C's (cause, concern and countermeasure); Status of action by actionee; Status of action by category; Control chart (PPC per week, average PPC and target); Summary with work beginning date/PPC/Status of the target achievement
f	Activity tracker (PowerApp)	**A**	Planning and control project	Status (in progress, not started, done); Category (discipline); Action; Actionee; Delivery Owner (organisation responsible); Document type; Planned start/Finish; Date; Completion Date; Reason overdue; Comments; Folder location/ PDF link/; Date Checked / Date approved
g	Risk dashboard (balance scorecards)	**A**	Risk assessment	-
p	Navisworks for clash detection, quality control and control of changes	**B**	Clash detection, visualisation, stakeholder's engagement	Issues identified by discipline
q	GIS for coordination	**B**	Identification of hazard elimination, support design decisions and stakeholder's engagement	Pre-construction, Construction and Handover Hazards and Constraints information.

*The project adopted SharePoint as a document management system, which supported the use of other digital tools for planning, control and coordination. **The tools **p** (Navisworks for clash detection, quality control and control of changes) and **q** (GIS for coordination) were identified during interviews, but the researcher was not able to analyse them during their use in project B.

Source: the author.

The purpose of the **stakeholders weekly meeting** (project meeting 1) was to contract management and change control discussion between the project manager and the client.

The **stakeholders' quarterly meeting** (project meeting 2) was similar to a focus group, in which pre-consultation and consultation events with general stakeholders, such as representatives of the general public or communities, and councillors were performed. The meetings were guided and organised by the Deputy Customer Manager, and occasionally the project manager, BIM manager and client also attended those meetings.

GIS was adopted as a collector software during the stakeholders' meeting (i.e. meeting with the community), helping to store land data and create a 'book of references' with information related to parcels adjacent to the project. The community was able to input details related to the land with the support of mobile computing during the stakeholders' meetings. During the public events, the tool enabled the collection of different kinds of data, e.g. vegetation, in which the users and community can attach comments to it, supporting design development.

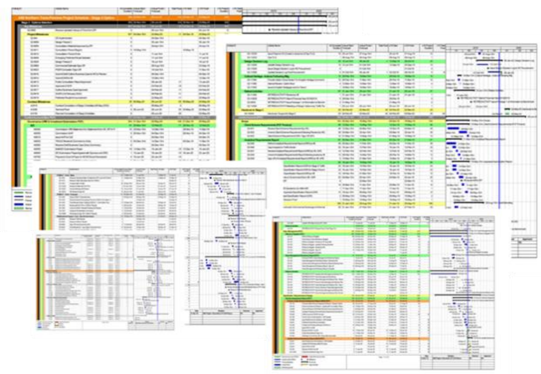
The milestones and deliverables defined and identified in the master schedule supported the phase scheduling, also titled in the company A as **collaborative planning session** (project meeting 3), which was similar to a workshop, and it was undertaken to develop a high-level design programme, which was reviewed every three or four months (or when required). The duration was, on average, 3 hours for each stage planned. The aims of the workshop were similar to those described in the embedded empirical study 1 (see section 4.2.2.1). The meeting structure was defined as: initial discussion (e.g. introductions, agreement of objectives and expected agenda – 30 min), collaborative planning (120 min), and final discussion (e.g. agreement about following steps – 30 min). Some team members did not fully engage in the meeting, as the structure of the session and the VM tools were not clear for them (Figure 77).

Figure 77 – EES2: Planning.

Source: the author.

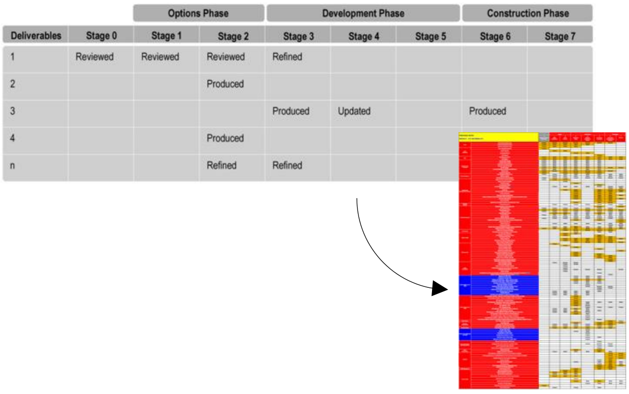
Collaborative planning sessions adopted the master schedule as a reference to make decisions. The master schedule (Figure 78) was a very detailed plan (33-page list of activities), which contained a set of deliverables (Figure 79). As there was a high level of detail in long-term plans, it was very time-consuming and difficult to update it.

Figure 78 – EES2: Master Schedule with Primavera P6.



Source: the author.

Figure 79 – EES2: Matrix of deliverables for each stage of the design process.



Source: the author.

Project B adopted analogue visual management tool to support the collaborative planning sessions (phase scheduling). The collaborative visual board with milestones and deliverables, as well as the whiteboards, had the same functions described in the project A. The collaborative board with milestones and deliverables provided the understanding of the interdependency between tasks and responsibilities among disciplines. The whiteboards were simple and easy to use, making it easier to get team members' engagement. Those boards were used to display (i) objectives; (ii) assumptions; (iii) key actions, (iv) deliverables (surveys), and (v) other topics (e.g. overview of the project).

In the collaborative planning session, collaborative visual boards were not effectively used, as very detailed information from the master schedule (a CPM network) was displayed. By contrast, participant observation indicated that the meeting had a high-level discussion and agreements. The main issues related to the use of those VM boards were pointed out by teams leaders and project manager : (i) the lack of understanding of how to use the tools, (ii) the overload of information detail within the board, (iii) the difficulty in maintaining the information up-to-date, recording and sharing properly the information and decision-making with geographically distributed teams, (iv) the lack of availability of the tool after the meeting, as there was a lack of space to display the VM tools in company A offices and the meeting rooms were shared between different projects.

Figure 80 – EES2: Collaborative boards supporting the phase scheduling.

Source: the author.

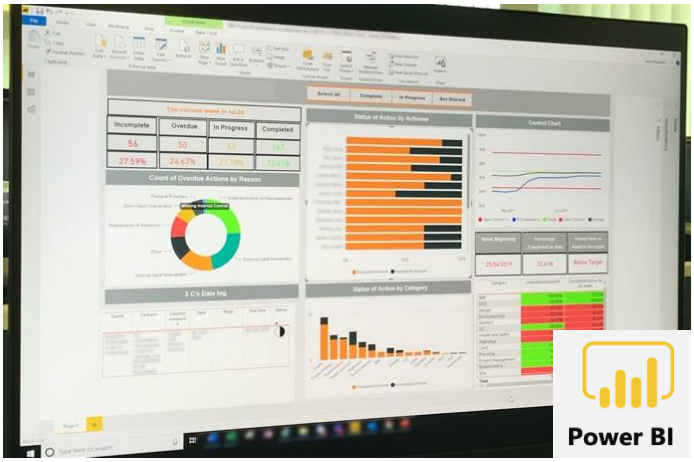
The aim of the **monthly progress meeting** (project meeting 4) was to discuss project progress, as well as the identification and removal of constraints. The meetings had the duration of around one hour, and were carried out monthly, both face-to-face and virtual, involving the project manager, team leaders, deputy customer manager and client. The company used a shared document with a monthly report, performance progress dashboards, and 4-week look-ahead programme report to support the meeting. The planning and control adopted the master schedule as a basis and activities were just pulled ('filtered') from the programme with the same level of detail, as a 5 pages report.

The structure of the meeting was analysed through participant observation and it can be generically described as: initial discussion (10-15 min), control (15-20 min), planning (20-25 min) and final discussions (5-10 min). It started with a general introduction, health and safety moment, review of the previous meeting minutes (approximately 10 minutes). Then, they discussed the progress report, identifying key achievements, lessons learnt and improvements/opportunities from the previous period (approximately 5 minutes). After that, the analysis and control of the progress related to the past period was done for each discipline (highways, traffic, environment teams, for example), and the team also reviewed the project milestones completion, taking approximately 15 minutes. In the third part of the meeting, the risk activities were captured and the team reviewed the 4-week look-ahead plan, taking around 15 minutes as well. Then, the percent plan complete (PPC) and the top 10 risks (e.g. additional time to identify landowners, delay and project running costs, the additional cost to re-run the traffic model) were verified and discussed (10-15min). At the end of the meeting, there was a temperature check of the team, to verify how much pressure the team was going through (5min).

A digital performance dashboard containing performance metrics (e.g. project progress, planning metrics) was used to support decision-making. The input data used for producing metrics came from information available in the activity tracker tool (d), which was easily updated by discipline design team leaders. Figure

81 and Figure 82 present the metrics displayed in the board: reasons for the non-completion of work packages, Percent Plan Complete (PPC), and the 3C's[ii] method to identify cause, concern and countermeasure. The digital dashboard also identified the status of the actions which can be filtered by the actionee, or category or discipline, as well as a control chart, supporting the monitoring of the PPC per week compared with the average PPC and the target. It mainly helped project managers and directors in analysing the team progress through weekly PPC and reasons for the non-completion of work packages. The interface is customisable according to the users and their management level; thus, project manager, directors and team member leaders have access to different interfaces and contents. The main categories for non-completion of plans are: underestimation of time/resources, external input unavailable and internal input unavailable. The company has a target of 75% of PPC to be achieved and the project manager can control the progress of the team and the status of planned and completed activities with this metric. Information about the digital performance dashboard was obtained through interviews with one project manager and two senior consultants (one working in the development of the tool and another one who was implementing the tool during the design development), as well as document analysis.

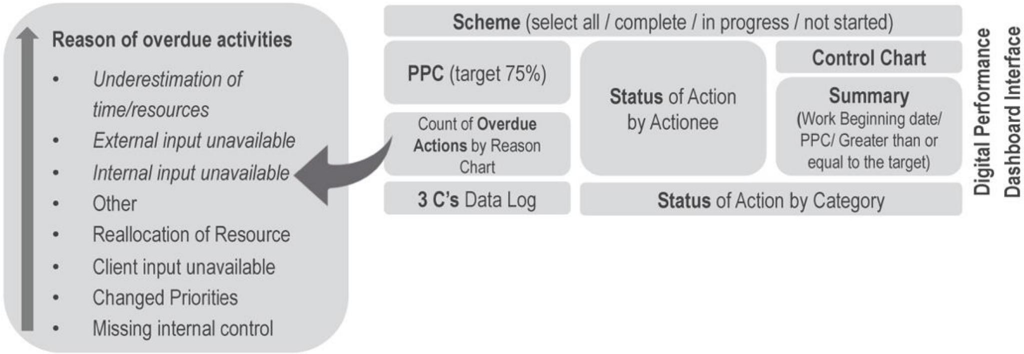
Figure 81 – EES2: Performance dashboard.



Source: the author.

[ii] 3C's is a problem-solving methodology, which is used to document concern, cause and countermeasure, encouraging employees to discuss about problems and actions.

Figure 82 – EES2: Performance dashboard 1 interface.



Source: the author.

Monthly risk review meeting (project meeting 5) consisted of reviewing activity risks within each discipline. Individuals one-hour meetings were undertaken within each discipline. The aim of the meeting was the analysis of activities risks on a monthly basis, also the analysis of the overdue risk actions, identifying the reasons for overdue. There was also a discussion about the degree of risk, the frequency of monitoring needed for each activity and the definition of risk mitigation activity (e.g. early involvement with archaeological bodies). Some examples of risk activities were described as: lands cost increase and install a concrete barrier. Those meetings involved team leaders, project manager, directors, and risk manager, which was charge of chairing the meeting. The risk management was not very well connected with the Last Planner System and presented an opportunity to improve.

Multidisciplinary design review meeting (project meeting 6) supported strategic design decisions, for example, for analysing the cost and impacts of design options. It involved key design team representatives, project manager, and directors. The frequency of this meeting depended on the stage the process, e.g. during the options phase, it was undertaken in an ad hoc frequency.

Weekly progress meeting (project meeting 7) helped to coordinate weekly and daily activities, through the (i) discussion about the plan; (ii) updating and controlling deliverables and activities, (iii) analysis and review of actions that were outside the master schedule, and (iv) review of requirements for the following assessments. The weekly progress meeting also helped in the review of activities according to the master schedule (with 2 weeks look-ahead planning). The planning and control also considered the master schedule as a basis and activities were just pulled from the programme with the same level of detail, as a 3 pages report document. The company used a shared weekly report to update activities from the past week and plan activities for the following one, which was populated by each team member individually before the meeting.

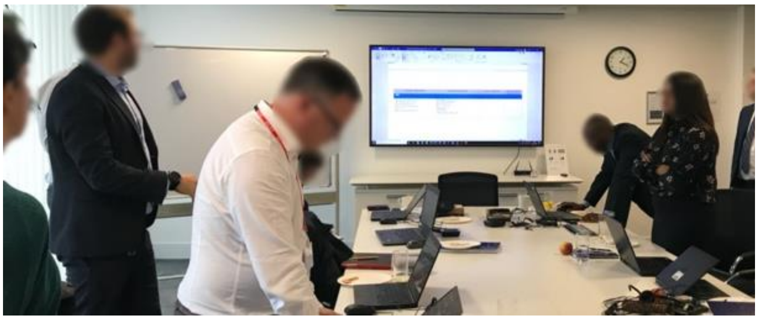
The meeting usually occurred online with shared screens and face-to-face with stakeholders who were at the office during the meeting. At the beginning and end of each meeting, there were always general discussions, introductions and agreements. The planning and control stages of the meeting were undertaken for each discipline involved in the project at that design stage, in sequence (e.g. stakeholders engagement team, design and engineering team, traffic team, economics team, outline business case team, environment team and project management team attended most of the meetings (during stage 02 of design development). For each discipline, the control of the progress and also the planning for the following week were done. At the end of it, there were 10 minutes for final discussions and agreements.

In strategic moments of the design process, e.g. end of each stage, a stand-up meeting was carried out (Figure 83 and Figure 84), in which stakeholders attended the meeting in person, as a way to integrate the team and celebrate the achievements. Usually, such meetings tend to be short (taking 45 minutes), as indicated by participant observation of weekly progress meetings and by interviews with the project manager and technical director.

Figure 83 – EES2: Stand up meeting (Discussion).

Source: the author.

Figure 84 – EES2: Stand up meeting (Planning and control - weekly report discussion).



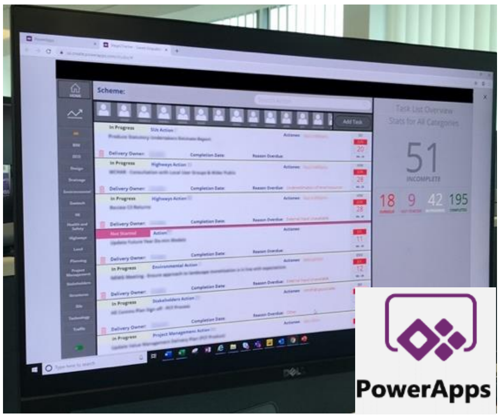
Source: the author.

The **lean call** (project meeting 8) supported the control of weekly and daily actions, through an update of activities, control of deadlines and identification of reason overdue. Only the disciplines involved in the stage 2 of the process, i.e. options selection stage, attended the meeting, allowing a dynamic and quick meeting (usually 30 minutes long). Planning and control occurred simultaneously, as progress control and planning for the next period were done for each discipline in sequence. There was an overlap of information regarding the weekly meetings (i.e. weekly progress meeting and lean call) and managerial tools adopted to support them. It was described as a waste of time which affected the lack of stakeholders' engagement with the management activities and tools to coordinate the design activities, as indicated by participant observation and interviews with team leaders.

The traditional process at company A used spreadsheets to control activities of all projects, which presented a lot of issues related to real time update, complexity to use, limited use by team members and high chance of error, as pointed out during the open interview and meetings.

The digital activity tracker was a tool adopted to support weekly meetings. Its interface was created, customised and developed considering the user's needs and company expectations, as explained by the senior consultant in charge of the tool development, during an open interview. In addition to that, the tool development processes occurred through iterative learning cycles as a way to improve the tool during its use in design development process. There was an internal employee responsible for this process, who had direct contact with team members, collecting feedbacks during the use. The tool was used at operational level, for supporting meetings between disciplines, but it could be also used to support operational activities inside each discipline.

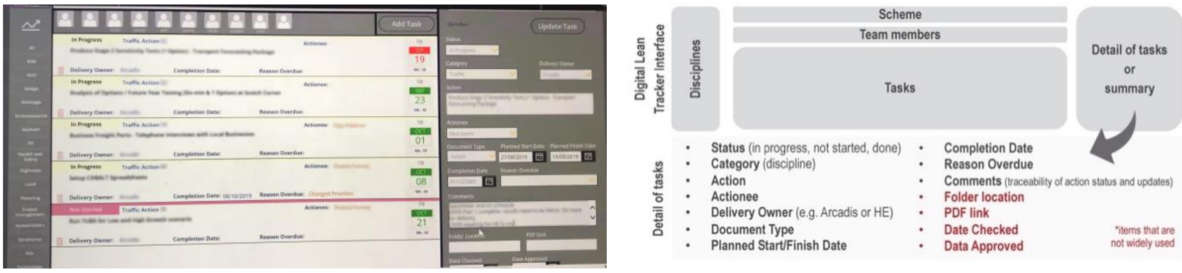
Figure 85 – EES2: Digital activity tracker.



Source: the author.

The aim of the digital activity tracker was to monitor activities by design discipline, and update tasks and actions, during the weekly meetings. The discussion was focused on the task completion, as well as the identification of reasons for overdue tasks (Figure 86). All team members had permanent access to this digital tool through diverse displays. During the meetings, the tool was displayed on the project manager's screen, enabling information to be shared among team members. The project manager used the area for comments inside of each activity to take notes every week about the situation of action, allowing the traceability of information.

Figure 86 – EES2: Digital activity tracker's interface.



Source: the author.

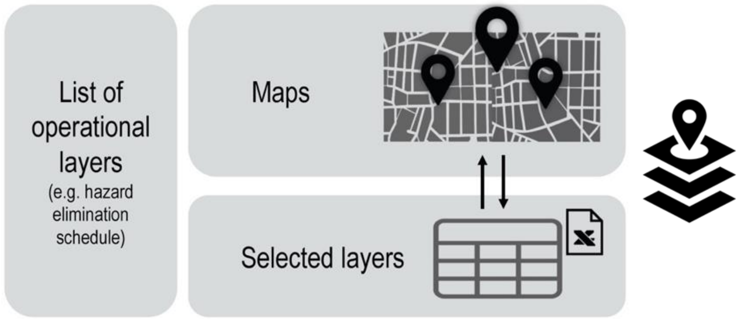
As described in project A, project B also presented **design coordination meetings** (Project Meeting 9), however, it occurred from the preliminary design stage and the researcher was not able to analyse the meeting and tools through direct or participant observations, just through interviews, document and VM analysis.

GIS started to be implemented recently at the company as a coordination tool, also supporting the visualisation and clash detection during the coordination meetings. The implementation of the tool was identified through interviews with the principal design manager and senior GIS consultant of the project B. It helped in gathering data, management and analysis, mainly related to the pre-construction information, focusing on health and safety. The information visualisation assisted in identifying patterns and design options, as well as in analysing the interdependencies between disciplines and different data collected.

The identification and elimination of hazards were the most common function during the option design stage, which consisted of a hazard control strategy to remove a process that is creating a risk for the design development, e.g. the existing buildings and adjacent user's lands can be potentially considered as a medium risk hazard for the option phase. All team members of the design had access and were able to visualise information through the tool, although just design leaders and project managers were allowed to input information. The client also had access to all data. The tools enabled the traceability of information during all project life cycle, supporting more consistent decision making. It was also possible to have all information in one place, supporting the management and analysis.

The tool presented challenges related to the input of information and its integration with the current database (see Figure 87), as pointed out by the principal designer, presenting issues to populate the tool and consuming a lot of time. It presented plenty of categories that should be filled in (around 34 categories), and there was a lack of information standardisation to guide the team members through filling the information during the design process, creating difficulties to stakeholders to use the tool correctly. Information was manually introduced into the tool and the lack of standards could lead to issues related to information update. It had a limited use by team members and team leaders, and a higher chance of error.

Figure 87 – EES2: GIS tool's interface.



Source: the author.

Daily calls or informal meetings (project meeting 10) were undertaken inside o each discipline to control the progress and to have activities update in a daily basis.

Lessons learnt meeting (project meeting 11) occurred at the end of each stage for discussing about lessons learnt from each discipline (e.g. project management, highways, traffic, geotechnical, drainage, structures). The meetings were carried out individually with each discipline. There was also an identification of potential improvements, besides a critical analysis of actions and decisions developed, evaluating which one should take forward or not to the next stage or project. A lesson learnt database (Figure 88) was created for each design discipline in each project. However, the information was fragmented (organised by project) and, hence, it was difficult to identify improvements for future projects in the company. Information about this workshop was obtained in interviews with the project manager and the technical director, as well as through document analysis (lessons learnt database).

Figure 88 – EES2: Lessons learnt database organised by project and discipline.

Disciplines	Main topics	Lessons Learnt	Improvements	Things we do well	Things not to take forward
Project Management	Leadership	≋	≋	≋ ✓	
	Delivery	≋			≋ ✗
	Performance Management			≋ ✓	
Highways	Design Development	≋	≋	≋ ✓	
	Design Communication	≋			≋ ✗

Source: the author.

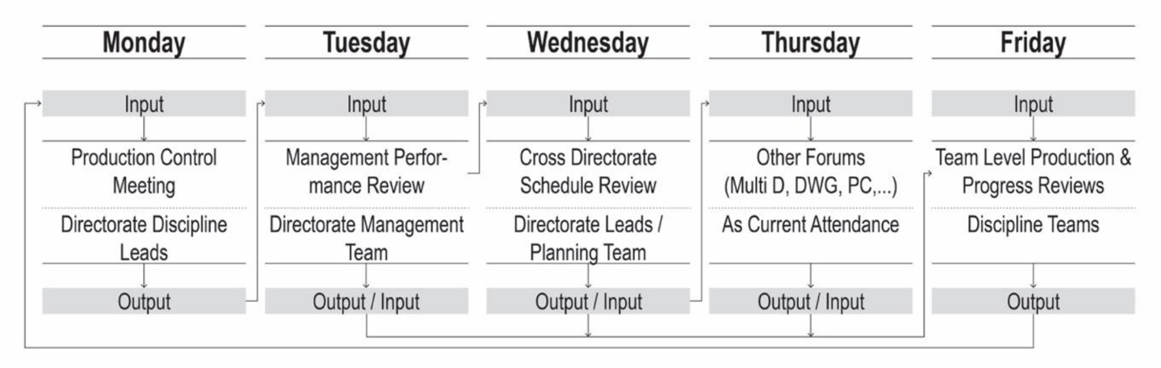
Lessons learnt workshop (project meeting 12) was held at the end of each project as an opportunity to disseminate the knowledge obtained during the different stages of each project. The review of lessons learnt involved several stakeholders (e.g. project manager, directors, team leaders and members, BIM manager), in a meeting with around 4 hours of duration. Information about this workshop was obtained from interviews with the project manager and the technical director.

5.2.4 Embedded Empirical Study 3 (EES3)

This embedded empirical study was limited to design planning and control due to the short period for data collection and analysis.

Weekly meetings (Figure 89) were implemented to control the consistency of the decisions, setting the project pace. There were five types of meetings hierarchically organised: production control (also entitled progress meeting in this research), management performance review, cross-directorate schedule review, other forums, e.g. team level production and progress review (see Figure 89 and Figure 90). The different levels enabled the group to look ahead and remove constraints before starting tasks. The existing structure of meetings was regarded as an initial guide and there was some degree of flexibility, if required. The following information about each meeting: (i) the aim of the meeting; (ii) the frequency of meeting; (iii) the agenda, in which all topics that should be discussed in each meeting were described; and (iv) the input and outputs needed for each meeting, enabling the stakeholders to obtain the identification of documents and information needed.

Figure 89 – EES3: Design Planning activities.



Source: the author.

The meetings are briefly described in Figure 90. The duration of meetings varied from 30 minutes to 1 hour.

Figure 90 – EES3: Design Planning activities (meetings structure).

ID	Activity	Aim	How	Frequency/ duration	Participant	Tools **
7	Weekly Progress Meeting	Establish the production, capture and mitigate of risks (4 Week Lookahead & Weekly Work Planning)	Virtual call	Monday Weekly 1 hour	Directorate discipline leaders	n
13	Management Performance Review	Support the planning, control and monitoring of the progress through weekly management review of KPIs.	Virtual call	Tuesday Weekly 30 min	Directorate management team	o
14	Cross-directorate Schedule Review	Collaborative cross-directorate Level review of current Level 2 project milestones based on any key changes from Directorates' Production Control.	Virtual call	Wednesday Weekly 1 hour	Directorate leaders and planning team	o
15	Other Forums	Discuss specific issues and challenges, and review progress, e.g. different meetings to support the discussion around different software	Virtual call	Thursday Fortnightly	As current attendance	-
16	Team Level Production & Progress Review	Flexibility to plan and control inside of each discipline	Virtual call	Friday Weekly	Discipline teams	j

*The meetings in which the researcher did participant observation were: Weekly Progress Meeting (7), and Management Performance Review (13). The other meetings were identified in interviews, discussions with key team members and document analysis
** See Figure 92, Figure 94

Source: the author.

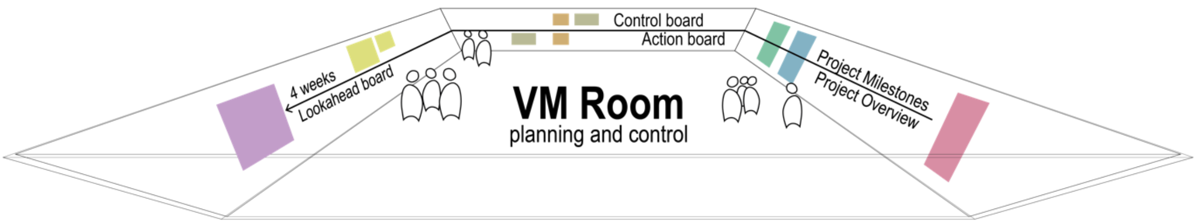
The aim of the **weekly progress meeting**, also called as production control meeting (Project Meeting 7), was to review weekly plans with directorate discipline leaders, through a collaborative discussion, in order to get an agreement on the schedule. It aimed to maintain the goals of the master schedule, check if the required resources were available, identify constraints and non-completed activities, and also identify issues that should be presented on management performance review and cross-directorate meetings. It was considered to be important that all stakeholders involved in this meeting understood their role as well as the required input. The meeting took around one hour, and the agenda usually covered the following topics: ongoing design key activities update, analysis of previous week production and actions review, planning of 4-week lookahead, commitment to current week's work plan, in addition to capture and migration of risks. The inputs for this meeting were: lookahead plan, activity tracker with discipline progress (i.e. BIM 360 Plan), risks schedule, and challenges identified since the previous meetings. The information output expected for this meeting was: PPC, reasons for the non-completion of work packages (BIM 360 Plan), and selection of issues for the cross-directorate meeting.

In the **management performance review meeting** (project meeting 13) project progress was reviewed against the master schedule, encouraging the early identification of issues, requirements, risks and opportunities; any relevant schedule or technical issue identified was selected to the cross-directorate meeting; The agenda was divided into three main phases: (i) a quick discussion about key project updates from management team, (ii) review of past week's production and performance metrics, focusing on non-completed activities, risk factors to critical path and 'what if' analysis, (iii) review actions and key deliveries tracker, (iv) identification of high risk activities and assign them to the specific teams; (v) confirmation of attendance on cross-directorate meeting (cross-directorate schedule review meeting) and agree areas of concern to be discussed in the next meeting. The inputs needed for this meeting were described as: performance metrics (PPC, reasons for non-completion activities, non-completed activities analysis), which were updated in advance in BIM 360 Plan, and relevant items were identified in the weekly progress meetings by directorate discipline leaders. The output information was: clear ownership of improvement activity and resolution actions, identification of items of concern to the weekly progress and cross-directorate meetings, as well as master schedule updates.

The **cross-directorate schedule review** (project meeting 14) is a collaborative review of project milestones against the master schedule by cross-directorate, and also a comparison of key changes coming from the weekly progress meeting; The latest schedule was revised, monitoring the project delivered and the compliance with the agreed plan, identifying risks and mitigating actions, through a collaborative review of the schedule on a weekly basis; The agenda was defined as: (i) analysis of milestones impacts and risks, (ii) review of master schedule critical path, (iii) confirmation of actions and owners, and (iv) identification of items of concern to other meetings (if required); The inputs for such meeting were described as latest master schedule, milestones strategic plan, items identified on weekly progress and management performance review meetings; whereas the outputs were related to the milestones agreed, an understanding of current master schedule and existing risks.

Both analogue and digital VM tools were used in Project C to support design planning and control, as presented below. Initially, a physical visual management room was used to support planning and control (Figure 91). Furthermore, this project also adopted the concept of Big Room, collocating the team members from different design companies and clients in the same office in London. Analogue VM tools from different planning levels were made available in the room, also encouraging face-to-face communication and informal meetings to take place around the boards. Consequently, it became to easier to get an understanding of the interdependencies between disciplines, as all stakeholders had easy access to a wide range of information. Data collection and analysis of analogue VM tools, VM room and big room were done considering the information that emerged during open interviews and meetings with the lean managers, as well as documentation, tools interfaces and photographs provided by the project team.

Figure 91 – EES3: Planning and Control VM room.



Source: the author.

The boards from the right side of the room were related to the planning level 1 and 2, presenting the project delivery milestones planning (see Figure 92). The deliverables were shown by discipline and by month. In the sequence, there were collaborative boards, supporting the identification of issues, entitled as (i) share information, (ii) control, (iii) action, (iv) look after (Figure 92). The room also presented VM tools to support the identification of activities that have been completed and reasons for non-completion (see Figure 92). On the left side of the room, there was a board supporting the 4-weeks-lookahead development, identifying main activities by discipline and the delivery date for the next 4 weeks (see Figure 92). Due to the lack of access to the office and to the face-to-face meetings, the analysis of how the traditional tools supported the managerial routines was limited.

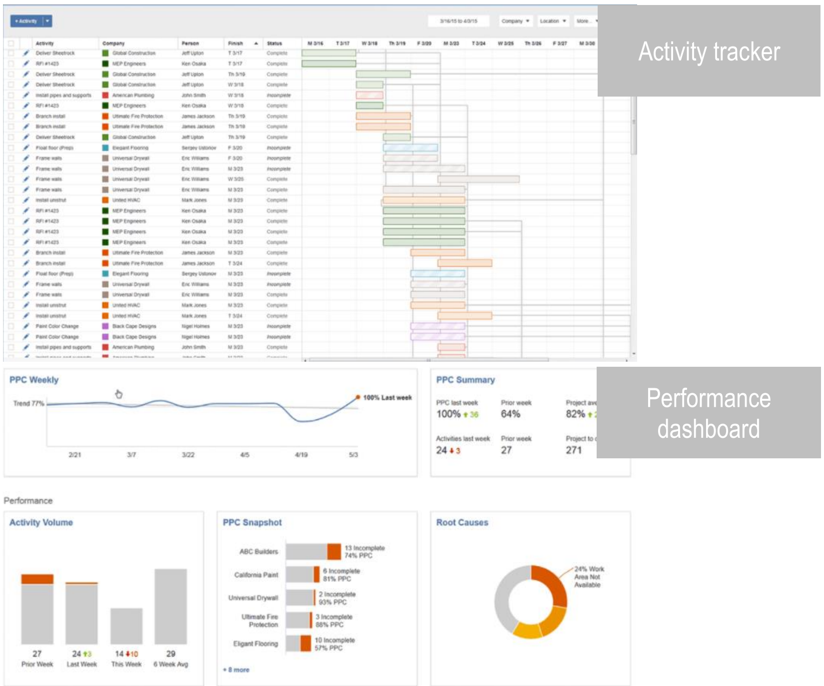
Figure 92 – EES3: Analogue Visual Tools.

ID	VM tools – Scale board	Information
h	Project Milestones Board (Milestones Heatmap)	Deliverables by discipline and month
		Delivery Date
i	4-Weeks-Lookahead Board	Activities by discipline
		Delivery Date
j	Activities Completed Board	Team
		Activity
k	Reasons for Non-Completion Board	Description of reasons
		Disciplines involved
l	Control Boards	Overall Performance
		PPC per week by discipline
		Average PPC by discipline
		Moving average by discipline
		Volume of activities by discipline
		Cumulative Reasons for Non-Completion by discipline
		Last Week Reasons for Non-Completion by discipline
		Non-Completed Activity Analysis by discipline
m	Action Board (3C's and Risk)	3 C's (Date, Concern, Cause, Countermeasure, Who, When, Status)
		Risks (Date, Risk, Mitigation, Who, When, Status)
r	Project Overview Board	Programme (Redesign programme, design programme)
		Process (Process mapping, process savings)
		DCO products performance
s	Look-after-people, success, and news board	People
		Successes (Date, Success, Best Practice, Author, Who, When, Status)
		News
t	Evolve Board (improvement ideas and lessons learnt)	Improvement ideas (Date, Idea, Action*, Who, When, Status)
		Lessons Learnt (Date, Lessons Learnt, Recommendation*, Who, When, Status)

Source: the author.

Due to the Covid-19 pandemic, some changes in the planning and control process as well as in the VM tools were made. A major change was that information fields had to migrate from analogue to digital platforms. The BIM 360 Plan supported design planning and control, presenting different information, such as activity tracker, weekly lookahead (Gantt chart) and performance metrics control (Figure 93); Microsoft Teams supported the digital environment as a platform to transfer information between team members. The tools and their functions are described in Figure 94.

Figure 93 – EES3: Planning activities through BIM 360 Plan (generic example of the tool interface).



source: Autodesk website

The activity tracker adopted to support the planning and control of activities was available to everyone all the time, being easily accessible to team members. BIM 360 Plan supported the track of non-completed activities and their reasons, being able to store and process the information very quickly, as pointed out in direct observations and open interviews. The activity tracker with weekly lookahead was used in the weekly progress meeting, supporting real-time information update. The performance dashboards 2 were based on the data collected through the BIM 360 Plan, which was considered as an input for the boards used in management performance review meeting and distributed for the team prior and after the meeting.

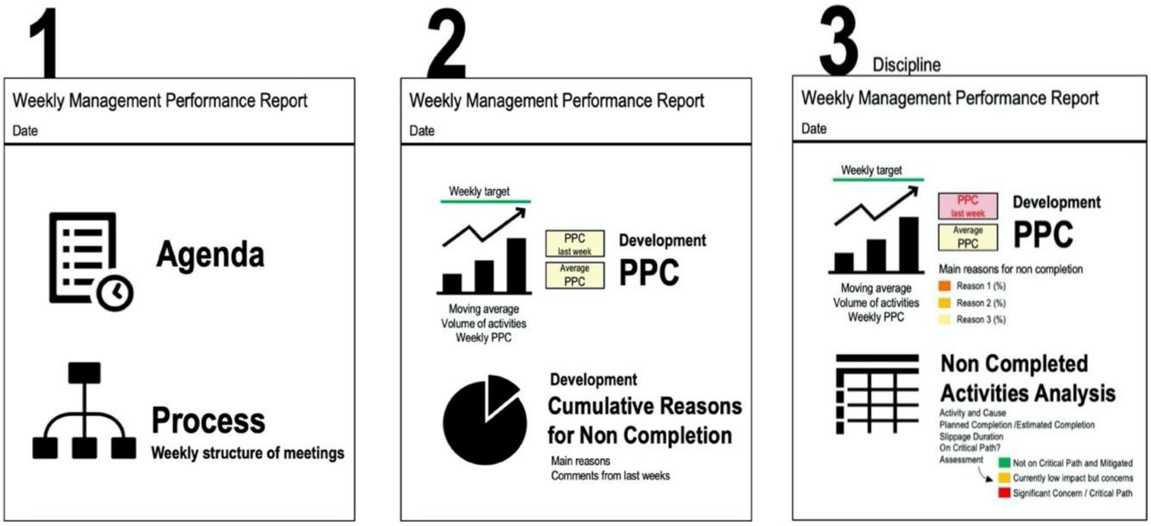
Figure 94 – EES3: Digital Visual Tools.

ID	VM tools	Information
n	Activity tracker with weekly lookahead (BIM 360 Plan)	Type (Task, Delivery)
		Activity Name
		Location (e.g. consents, construction, environment)
		Company/Disciplines
		Person
		Finish Date
		Status (Complete, Committed, Incomplete - Root Cause, Delay, New Finish Date, Notes -, Open)
		Current PPC
o	Performance Dashboards 2 (Figure 95)	PPC per week
		Average PPC
		Moving average
		Volume of activities
		Cumulative Reasons for Non-Completion
		Last Week Reasons for Non-Completion
		Non-Completed Activity Analysis

Source: the author.

Three different dashboards were adopted to support the meeting. The first dashboard had the agenda and the meeting structure for the week, in order to make the aim of each meeting explicit, as well as the stakeholders involved and the days of the week in which each of them occurred. The second performance dashboard had (i) the PPC from the previous week and the overall PPC, also identifying the moving average, and the number of activities; and (ii) identification of the reasons for the non-completion of activities, including the analysis of the main causes. The last performance dashboard was also produced for each discipline, so the number of boards could vary according to the number of disciplines involved. It also included a detailed analysis of the planning failures, such as the comparison between planned and real completion, slippage duration, identification if the activity was in the critical path, and risk assessment.

Figure 95 – EES3: Performance dashboards 2.



Source: the author.

5.2.5 Discussion

The main contributions of the empirical study were associated with the

- Identification of good practices and improvement opportunities related to Design and Visual Management, which supported the development of the guidelines.

- Relevant VM conceptual contributions: (i) refinement of VM types identified in the exploratory study (type A and type B) and identification of a new VM type (type C), which can be considered as a useful classification to describe VM tools in design; (ii) identification of two key categories of VM tools to support planning and control (type A): status and performance dashboards; (iii) development of a process model for integrated design management and VM types; (iv) refinement of collaboration and communication approaches, proposing a new category and adapting the taxonomy suggested by Ugwu et al. (1999) and Anumba et al. (2002), i.e. synchronous Distributed and Face-to-face Collaboration (SDFFC); (v) proposition of a set of VM requirements for design management; and (vi) identification of VM impacts in design management.

5.2.5.1 Good practices and improvement opportunities related to Design and Visual Management

The main good practices identified in the investigation were related to the definition of three hierarchical levels of design planning and control, in which collaboration and decentralised decision-making were encouraged. There was a consistent **structure for design planning and control meetings** in the three embedded empirical studies, with a clear definition of **tools and responsibilities,** especially in the embedded empirical studies 2 and 3. This was important to keep the meeting focused and efficient, enabling greater engagement and understanding among the team members as well as limiting meeting duration. There was a consistent agenda of meetings across the different planning levels in the embedded empirical study 3, with well-established aims and frequencies.

There were lean managers who were in charge of guiding meetings as neutral facilitators in some meetings. They also supported the transition to digital design management in the empirical study 3. Those managers helped to keep meetings focused and efficient, ensuring that all participants understood the aim of each meeting, and supported the use of VM tools. This enabled greater trust from the stakeholders involved, helped to reduce the number and duration of meetings, and ensured stakeholders needs were met (avoiding the need for parallel meetings to discuss the unsolved problems).

An initial effort and work from key members in the **development and implementation of the design management process** through different planning levels was identified in the embedded empirical study 3. However, **the VM tools for activity tracker and performance dashboards emerged through a bottom-up approach** in that specific study, which made it easier to consider the needs of the design team. The development of VM practices and standardised templates was also supported by Lean managers, enabling the development of a common communication approach.

Training was promoted to improve design team members' understanding and engagement with the planning and VM tools adopted. In the empirical study 3, set-up training, also called as lean awareness training, was encouraged. Moreover, some master classes on specific tools, processes or methods were held in the company A when required.

The **early client involvement** through collaborative meetings allowed the identification of requirements in the front-end design stages. In fact, the client was able to attend to strategic, tactical, and operational design meetings. This form of involvement of client representatives helped to reduce the number of later design changes.

The **implementation of a big room** (empirical study 3) encouraged informal discussions, increasing transparency across different design disciplines and supporting the fast resolution of design issues. Co-location encouraged an interactive process among design team members, as well as a collaborative process and a faster transfer of information between disciplines and client. It facilitated multidisciplinary team integration as it allowed more effective communication when the team was working in the same environment – facilitating formal and informal access to information. The big room also became an informal meeting place for the teams, supporting a shared understanding between stakeholders, as suggested by Koskela et al. (2018).

The implementation of new digital tools, such as digital activity tracker and performance dashboards in the empirical study 2 and 3**, and the introduction of improvements of those tools along the implementation process**, contributed to improve collaboration between stakeholders which were distributed in different places and offices.

The main improvement opportunities identified in the research work were related to the **fragmented flow of information between stakeholders**, which analysed from two perspectives: (i) users' perspective, highlighting the lack of team members' engagement in the use of tools at all levels; and (ii) tools' and process perspective, concerned with the inadequacy of tools in relation to the process, which can be divided into three categories: The need for a cultural change regarding regular sharing of information; excess of information combined with lack of information prioritisation; and ineffective use and transfer of information between disciplines.

There was a top-down approach to implement Last Planner and Visual Management within the company, as a client requirement. However, there was evidence from the three empirical studies that the company implemented VM in a fragmented way. There was **a lack of formalised visual management system,** as VM tools were used at specific points in time during the process and for specific activities. Thus, VM should be taken as a strategy. Furthermore, there was a **limited use of the VM tools** by stakeholders due to difficulties in accessing the tools or lack of information, related to the digital performance dashboards and coordination tools. There was no clarity about how to use the performance dashboard tool and where to find information, for example. Consequently, team members and discipline leaders were unaware of such performance dashboards at an operational level. Hence, there was an opportunity for all team members to benefit from the use of the tool in the future by better integrating it in the process and increasing its availability and accessibility.

There were issues mostly related to the **understanding of company processes by all team members**. Company A had a complex managerial structure and a multitude of internal and external stakeholders involved in the design process. The relationship between all stakeholders varied depending on the size of the project and the type of client. Although the company had its own design management process, it had to be adapted to client's needs and requirements as well as to external stakeholders' processes in joint-ventures or other partnerships, e.g. company B, C, D.

Moreover, there was a **poor engagement** of some team members towards the definition of process improvement activities in the empirical studies 1 and 2**.** The decisions regarding lean strategies implemented in those projects were taken at the strategic level, without enough involvement of the staff at operational levels.

There was an **excessive level of detail in long-term plans** in order to attend the client requirement**,** making it difficult to be updated. It was not helpful to plan design activities in detail far in advance of their delivery due to variability in design activities. The long-term plans should be simpler and more visual, allowing a better control (e.g. collaborative boards with milestones). The **excess of information** in design planning and control tools besides **unnecessary detail** of coordination tools made it difficult to regularly update, track and monitor the progress and problems at tactical and operational level as well. It can lead to an overlap of information in meetings and VM tools, e.g. weekly progress meeting and lean call (embedded empirical study 2), resulting in waste of time and lack of stakeholders' engagement in those meetings.

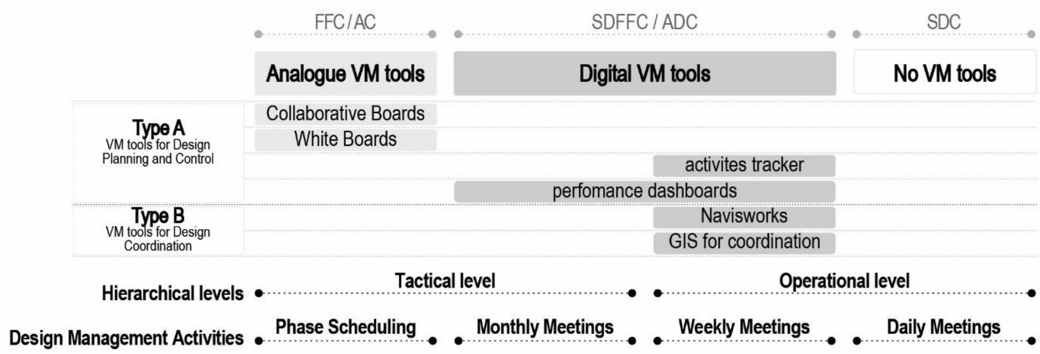
5.2.5.2 Relevant VM conceptual contributions

The tools analysed on the empirical study were classified according to the types A, B and C; whether digital or not; the hierarchical managerial level; and whether dynamic or static.

Figure 96 represents the relationship between managerial activities and VM tools, considering the communication and collaboration approaches which supported each of those implementations. The empirical study was initially defined by four different levels of planning, i.e. phase scheduling, monthly meetings, weekly meetings and daily meetings, presenting different levels of information in each of them. In this investigation, digital VM is not only related to the way information is displayed, but also to how the users interact with it, the visual and non-visual work as described by Nicolini (2007), so the definition of different planning levels is relevant to characterise the context in which they are used.

The discussion is focused on type A and B, considering that the researcher was able to triangulate the different sources of evidence through qualitative analysis. The VM tools analysed were mostly classified as Type A. By contrast, type B VM tools was not widely found in the company, indicating a lack of emphasis of VM on product design - only two tools were identified.

Figure 96 – Relationship between managerial activities and VM tools - Main empirical study (main source of evidence: embedded empirical study 2).



Legend: Face-to-face Collaboration (FFC), Asynchronous Collaboration (AC), Synchronous Distributed Collaboration (SDC), Asynchronous Distributed Collaboration (ADC), Synchronous Distributed and Face-to-face Collaboration (SDFFC)

Source: the author.

Type **A** VM tools supported mostly tactical and operational hierarchical managerial levels. Different VM tools were used in an integrated way to support meetings. There was a potential to increase their application range to support the hierarchical cascade of design decision-making, collaboration, integration, and communication through the organisation. The tools adopted at the tactical level, e.g. performance dashboards and collaborative boards with milestones and deliverables, supported planning in phase scheduling meetings and also planning and control in monthly progress meetings. The weekly meetings at the operational level also received support of design planning and control VM tools, e.g. activity tracker. One of the main contributions of this analysis was associated to the understanding of two key categories of VM tools to support planning and control (type A): status and performance dashboards.

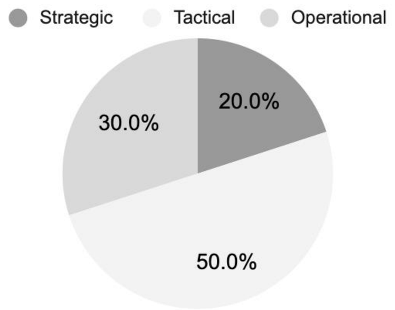
The tactical level was supported by both analogue and digital tools, whereas the operational level had only digital tools implemented. For example, the decisions made at face-to-face (FFC) collaborative planning sessions (phase scheduling) were supported by analogue collaborative visual boards. By contrast, daily meetings at the operational level within each discipline were carried out through daily calls, in which some level of informal control was performed, and information transfer occurred through synchronous distributed communication (SDC). The digital activity tracker and performance dashboards implemented in weekly progress meetings were mostly adopted through synchronous distributed and face-to-face collaboration (SDFFC), as a part of the team was co-located and the other part was working from different offices in the UK.

The adoption of type **B** VM tools occurred mainly in monthly and weekly meetings, with the potential to support daily meetings as well. In monthly meetings, the VM tools mostly supported coordination and quality control of product design. The tools implemented at weekly meetings supported coordination, quality and change control, as well as model visualisation. At the operational level within each discipline, i.e. daily meetings, the tools had the potential to be mostly adopted as model visualisation. The analysis of type B VM tools provided an understanding of the product models adopted as a digital visual tool**.**

The embedded empirical study 2 had 31,8% of the 22 VM tools analysed, while the embedded empirical study 3 had the largest number of visual tools (50% of 22) to support design planning and control, mostly due to the fact that the design team was initially co-located, there was a planning and control VM room implemented, and the tools were implemented at different managerial levels. The majority of tools used in the embedded empirical study 2 was digital.

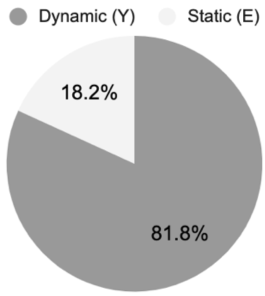
Also, most of the tools identified were related to tactical meetings (50%), i.e. phase scheduling and monthly lookahead meetings. VM tools at this managerial level were more embedded within the company, as the stakeholders were familiar with practices from previous projects, and they were used to support collaborative practices. Operational meetings, such as weekly meetings, had 30% of VM tools implemented, and only 20% of the tools were used in strategic meetings. Also, 81,8% of the VM tools presented a dynamic character, i.e. they were flexible and easy to change, increasing the potential of implementing them for collaboration, as suggested by Isenberg et al (2011).

Figure 97 – Nature of VM tools



Source: the author

Figure 98 – Digitalisation level

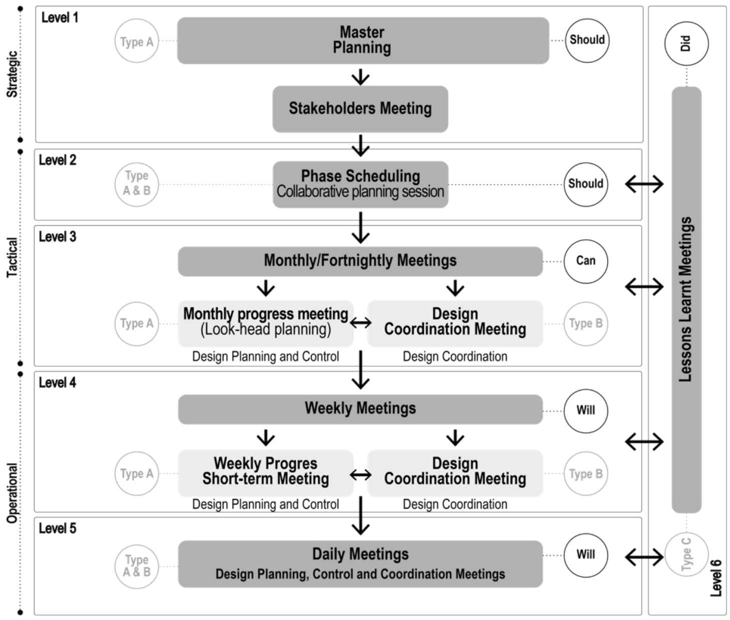


Source: the author

Considering the improvement opportunities identified in the empirical study, **a process model for integrated design management and VM types was proposed as an improvement for the company existing approach** (see section 5.2.1), highlighting the importance of understanding the nature and main characteristics of the VM tools required for the design management (see section 6.1). It considered six design management levels (**Error! Reference source not found.**), which are: (i) level 1, master planning at strategic level; (ii) level 2, phase scheduling at tactical level; (iii) level 3, monthly or fortnightly planning and coordination meeting at tactical level (lookahead meeting); (iv) level 4, weekly planning and coordination meetings at operational level between disciplines (commitment meeting); (v) level 5, daily planning and coordination meetings at operational level within disciplines; and (vi) level 6, described as continuous improvement activities, which can occur at the end of each stage, milestone or project allowing different improvement cycles.

One of the key differences in relation to the approach currently adopted by the company is related to a clear definition of monthly and weekly progress meetings, e.g. avoiding an overlap of information and VM tool adopted in the weekly progress meeting and in the lean call. It also proposes a formalisation of the daily meetings, for design planning and control, and design coordination activities, as a way to encourage shorter continuous improvement cycles in the project, in which progress is monitored on a daily basis.

Figure 99 – Model for integrated design management and VM tools.



Source: the author.

Level 1 and **Level 2** can adopt VM as a support for the design planning and it does not require a high frequency of update since the meetings are usually quarterly (phase scheduling) or at the beginning of a project (master planning). This planning level involves a greater number of stakeholders from different parties, such as managers, directors, team leaders, client representative, contractor representative and sub-contracted companies' representatives.

Level 3 involves monthly or fortnightly meetings enabling the coordination, planning and control of activities, through the development of a 4 weeks look-ahead plan. The flexibility of the tools represents an important aspect of the VM types adopted in this level, as the tools should provide context-relevant information as well as allow flexibility to make changes every four weeks. This level requires status and performance dashboards, as well as product models.

Level 4 requires VM tools with the same requirements as level 3, also adopting the status dashboards to support the planning meetings and product models to support model visualisation within coordination meetings. This level requires a high frequency of update since the meetings are carried out in weekly basis, emphasising the importance of easy accessibility and availability of information in this management level.

Level 5 is described as daily meetings inside of each discipline, adopting the VM types of tools which emphasise the control of activities and model visualisation. This type of VM tools involves the team members of each discipline and requires an independent use of the tool by them, as well as the flexibility to make changes on a daily basis. Level 6 should adopt VM tools to support the continuous improvement, however, it will not be detailed in this research study.

Figure 100 presents a classification of the VM tools according to collaboration and communication approaches adopted to support the managerial routines described above. Document and information management systems (e.g. SharePoint, ProjectWise, Microsoft Teams) provided means for distributing information, enabling the creation of an environment in which a potential virtual big room can be easily implemented. However, monthly and weekly meetings were mostly carried out through a combination of both face-to-face and virtual meetings, as part of the team was co-located and the other part worked from different locations. **The new approach of communication and collaboration was called by the researcher as Synchronous Distributed and Face-to-face Collaboration (SDFFC) and it is also considered as a contribution of this research.**

Figure 100 – Collaboration and communication approaches implemented

	Same time	Different times
Same place	**Face-to-face Collaboration (FFC)** Weekly stand-up progress meeting (7), Collaborative Planning Session (3), Daily meetings (10), Lessons Learnt Workshop (12), Stakeholders Quarterly Meeting (2), Stakeholders Weekly Meeting (1)	**Asynchronous Collaboration (AC)** Planning and control VM room (embedded empirical study 3)
Different places	**Synchronous Distributed Collaboration (SDC)** Stakeholders Weekly Meeting (1), Lean calls (8), Monthly Risk Review Meeting (5), Daily meetings (10), Lessons Learnt Meeting (11), Lessons Learnt Workshop (12), Management Performance Review (13), Weekly Progress Meeting (7), Cross-directorate Schedule Review (14), Other Forums (15), Team Level Production & Progress Review (16)	**Asynchronous Distributed Collaboration (ADC)** Communication through SharePoint, ProjectWise, Microsoft Teams
Both same place and different places *	**Synchronous Distributed and Face-to-face Collaboration (SDFFC)** Monthly Progress Meeting (4), Multidisciplinary Design Review Meetings (6), Weekly Progress Meeting (7), Design Coordination Meetings (9)	-

* Category proposed in this investigation

Source: the author.

The VM requirements identified in the literature review (see section 3.7) were refined in the empirical study**. The refinement of a set of constructs was considered the main contribution of this investigation.** The constructs identified and refined are: **simplicity (R1), information standardisation (R2), information availability (R3), information accessibility (R4), flexibility of tools (R5) and information traceability (R6).** Some constructs were adapted from the traditional VM context to the digital context, and others were adapted from digital tools to the VM context.

The characteristics analysed were relevant to the present research work and context, however, the VM requirements are not only limited those ones. In addition to that, the refinement of those constructs was characterised by the enhancement of VM requirements from analogue tools, such as simplicity and information standardisation. The simplicity emerged as one of the main requirements in order to engage all stakeholders with the use of the tool, enabling an easy understanding of tools' objective, as argued by Saurin, Formoso and Cambraia (2006). Moreover, the information and procedures standardisation emphasised the relevance of providing only the information or element required, in order to facilitate the user's understanding and define optimal process/product parameters, so it becomes easier to control repetitive tasks or situations, as suggested in the literature (TEZEL et al., 2015; TEZEL; KOSKELA; TZORTZOPOULOS, 2016).

This investigation also highlighted new VM constructs, as flexibility and information traceability. Flexibility was a key aspect to support the update of information through dynamic interactions, as discussed by Eppler and Bresciani (2013), while the information traceability encouraged systematic approaches to store, track and report information across the project process, as also mentioned by Whyte, Tryggestad and Comi (2016). This research work also explored the difference between information availability and accessibility constructs, which are considered key aspects of digital tools in order to allow an easy access to real time information.

Those constructs were used to assess the VM tools implemented, considering three different levels of adoption, which are: **full, partial, and non-adoption** (see Figure 101 and Figure 102), based on the perception of the research team. A specific definition was adopted for each construct considering the context of the company, as follows: (i) simplicity: easy understanding of the tool objective and easy to use, (ii) information standardisation: accurate information delivery and easy information prioritisation, (iii) real-time information availability and right amount of information available, (iv) information accessibility: easy information access and update, (v) flexibility of tools: flexibility to make changes and context-relevant information delivery, and (vi) information traceability: easy storage and tracking of accurate data. The implementation level for each requirement was associated with these specific definitions, if the tool had all of them, it was classified as full adoption. If the tool had some of the characteristics, it was classified as partially adopted. Finally, if the tool did not present any of the specific characteristics for a requirement, the requirement was classified as non-adopted.

From the 22 VM tools identified in company A, only 9 VM tools were further analysed according to the adoption of the VM requirements, due to the fact they were well integrated in design management and the researcher was able to cross analysed data collected from different sources of evidence, as explained in section 4. Figure 101 refers to the main tools related to the design planning and control, both analogue and digital, such as: activity tracker (f), activity tracker with weekly lookahead (n), performance dashboard 1 (e), performance dashboards 2 (o), collaborative planning board with milestones and deliverables (a), whiteboards with key assumptions, actions, risks, opportunities, and deliverables (b/c/d). The collaborative planning board with milestones and deliverables was adopted in the embedded empirical study 1 and 2 (EES1 and EES2) in different ways, considering different visual and non-visual work, so they were analysed separately.

Figure 101 – Classification of VM tools according to VM requirements – Type A (digital and analogue).

VM requirements	Type A						
	Digital				Analogue		
	Activity tracker (f)	Activity tracker with weekly lookahead (n)	Performance Dashboard 1 (e)	Performance Dashboards 2 (o)	Collaborative board with milestones and deliverables (a – EES1)	Collaborative board with milestones and deliverables (a – EES2)	Whiteboards (b/c/d)
Simplicity (C1)	A	A	A	A	A	PA	A
Information standardisation (C2)	PA	A	PA	A	A	PA	NA
Information availability (C3)	A	A	PA	PA	PA	PA	PA
Information accessibility (C4)	A	A	PA	PA	NA	NA	NA
Flexibility of tools (C5)	A	A	A	A	PA	PA	PA
Information traceability (C6)	A	A	A	A	NA	NA	NA

Legend: Adopted (A) Partially adopted (PA) Not adopted (NA)

Source: the author.

Figure 102 refers to the main digital tools related to the design coordination, i.e. Navisworks for clash detection, quality control and control of changes (p) and GIS for coordination (q).

Figure 102 – Classification of VM tools according to VM requirements – Type B (digital).

VM requirements	Type B	
	Digital	
	Navisworks for clash detection, quality control and control of changes (p)	GIS for coordination (q)
Simplicity (C1)	PA	NA
Information standardisation (C2)	A	PA
Information availability (C3)	PA	NA
Information accessibility (C4)	NA	PA
Flexibility of tools (C5)	PA	PA
Information traceability (C6)	A	A

Legend: Adopted (A) Partially adopted (PA) Not adopted (NA)

Source: the author.

Figure 103 represents the relationship between types of VM tools, VM requirements adopted, and digitalisation level. As a result, it is possible to conclude that analogue tools lack some key requirements for VM, such as flexibility of tools and traceability of information.

Figure 103 – Number of VM tools for each type of VM tools, VM requirements adopted, and digitalisation level.

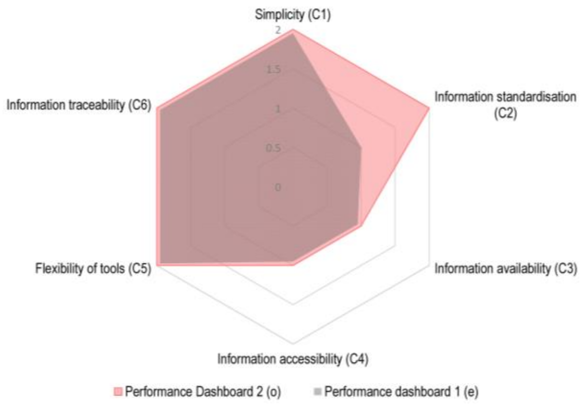
Source: the author.

The use of some digital VM tools, such as **performance dashboards** (e/o) **and coordination VM tools** (p/q), was limited due to difficulties faced by team members in accessing the right information or the tools. In fact, the company recently started to encourage the use of digital performance dashboards, thus, those tools were in the early stages of implementation across the company. Those tools were based on information stored in a cloud system, and users had not enough skills and knowledge in using them effectively. The difficulties were also associated to a lack of ownership when adopting digital VM tools, and it presents the potential to be further explored in future researches. Achieving a sense of share ownership is one of the key VM functions of traditional approaches, as described by Tezel, Koskela and Tzortzopoulos (2016), which can also support the achievement of company's strategic goals.

The performance dashboard 1 (e) was not easy to access, considering there was no clarity about how to use the tool and where to find the information. Consequently, team members and team leaders were unaware of such performance dashboard 1 at an operational level. The adoption of the tools was limited to the project manager as a way to control the progress only in monthly progress meetings. There was also a need to decentralise the use of performance dashboard 1, which can be achieved by giving project teams access to the dashboards, enabling them to have more responsibility to control and evaluate their own activities. The integration of the performance dashboard 1 in the weekly meetings had the potential to support the adoption of the tool, whereas initial training to introduce the tools' functionalities and aims to all stakeholders can provide an understanding of how to use and access. The information accessibility requirement was partially adopted in the performance dashboards 1 and 2 (Figure 104) and it was non-adopted in the clash detection tool (Figure 105).

Some specific metrics from the performance dashboards 1 and 2 were sent in reports to the team members as a static information, emphasising the lack of real-time information availability (information availability was partially adopted, as illustrated in Figure 104). There were some challenges related to the regular sharing of information of the **clash detection/visualisation** (p) tool, as teams tended not to share information as often as it would be necessary. This difficulty was also related to the partial adoption of the information availability requirement (Figure 105), as the right amount of information was not available when needed during the design process.

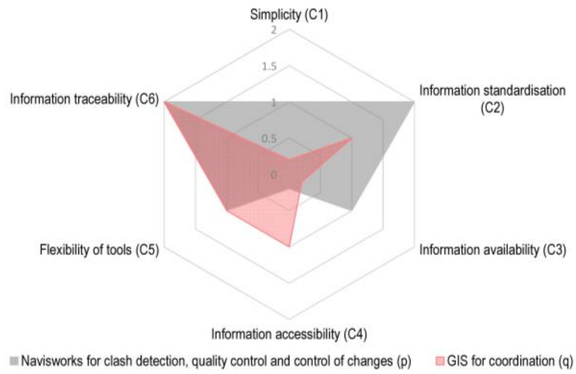
Figure 104 – Relationship of performance dashboard (type A) and VM requirements



Legend: Adopted - 2 / Partially adopted – 1 / Non-adopted - 0

Source: the author

Figure 105 – Relationship of coordination tools (type B) and VM requirements.



Legend: Adopted - 2 / Partially adopted – 1 / Non-adopted - 0

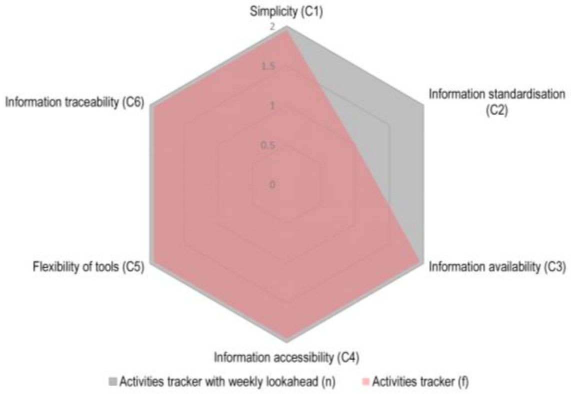
Source: the author.

The overload of information and unnecessary details led to waste, such as misunderstandings, and, when combined with a lack of information prioritisation, it caused issues related to the effective use of information and the selection of the right information (for the right purpose). It can also affect the simplicity and flexibility of tools. The excess of information created by the overload of information available resulted in problems to find and select the information required and, consequently, affected the engagement of the team with the tool. Furthermore, it also created barriers to access and update the information. Thus, simplicity and flexibility of information requirements were identified in the **coordination tools** (p/q) as partially or non-adopted concepts.

The activity tracker adopted or partially adopted most of the requirements (Figure 106). The **activity tracker** (f) and the **activity tracker with weekly lookahead** (n) were characterised by the full adoption of the concepts of availability and accessibility of information, as they had real-time information availability and the right amount of information available, which was filtered according to the meeting and the disciplines involved in the meeting. The information was also easily accessible by all team members, allowing them to use and update the weekly planning to support design development activities prior to the collaborative meetings.

The analogue tools, such as **collaborative planning boards** with milestones and deliverables, as well as **whiteboards**, presented a limited adoption of the requirements as expected since the requirements were developed to digital VM tools (Figure 107). The whiteboards (b/c/d) were characterised mostly by the simplicity requirement, allowing a greater engagement of stakeholders in their use during collaborative planning sessions. The collaborative boards (a) in the embedded empirical studies 1 and 2 presented different VM requirements adopted due to the fact that the tools were developed in different ways and the non-visual work was different in each study as well. It was more integrated in the embedded empirical study 1 and the stakeholders had previous experiences with collaborative practices, supporting a greater engagement, and information simplicity, in using it. There was a lack of accessibility of the tool after the meeting, as there was a lack of space to display the VM tools in company A offices and the meeting rooms were shared between different projects. There was no information traceability for analogue VM tools; the team members highlighted there was rework within the transfer of information between the collaborative boards and the management tools adopted by the company to support strategic decisions. The flexibility was also limited, being classified as partially adopted since it enabled easy changes, but it did not fulfil mobility and shorter information feedback requirements.

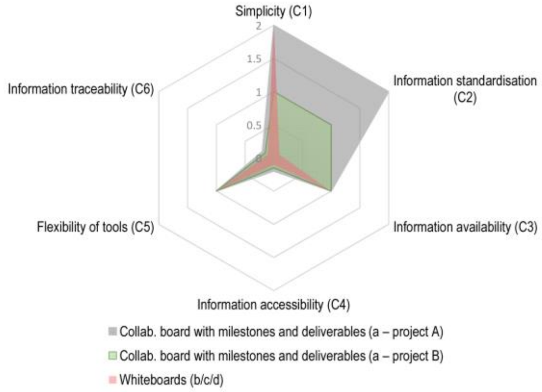
Figure 106 – Relationship of digital activity tracker (type A) and VM requirements



Legend: Adopted - 2 / Partially adopted – 1 / Non-adopted - 0

Source: the author.

Figure 107 – Relationship of analogue collaborative boards (type A) and VM requirements.



Legend: Adopted - 2 / Partially adopted – 1 / Non-adopted - 0

Source: the author.

The use of VM tools in design management needs to be relevant to the entire team, and, as a consequence, they can benefit from work routines, adding value to the design process through effective interactions. Figure 108 identify the **users' involvement as senders and receivers of information for each VM tool**. The information transfer between stakeholders was classified according to the users' involvement, described as 'one-to-many', 'many-to-one' and/or 'many-to-many' (Figure 108), as suggested by Brandalise (2018).

Both digital type A and B VM tools emphasised the concept of a boundary object, since they responded to different concerns simultaneously and were adopted as a common reference point between users, as argued by Nicolini (2007), in order to allow greater interaction and coordination. Digital VM tools engaged more users than analogue VM tools in their use and there were more stakeholders involved in the information input and output process considering the teams (located in different offices and places) were able to easily communicate and access the digital tools. The collaborative board with milestones and deliverables, as well as whiteboards were also characterised as 'many-to-many' interactions. However, those tools did not have information traceability, availability, and accessibility.

Figure 108 – Identification of users involved in the transfer of information

Users		Receiver: One	Receiver: Many
Sender	One	-	· Navisworks for clash detection, quality control & control of changes (p), · GIS for coordination (q)
Sender	Many	· Performance dashboard 1 (e), · Navisworks for clash detection, quality control & control of changes (p)	· Activity Tracker (f), · Activity tracker with weekly lookahead (n), · Collab. board with milestones & deliverables (a), · Whiteboards (b/c/d), · Performance Dashboards 2 (o)

Source: the author based on Brandalise (2018).

The activity tracker (f), activity tracker with weekly lookahead (n), collaborative planning board with milestones and deliverables (a), and whiteboards (b/c/d) had a large number of people sending and receiving relevant information to support design planning and control. The classification can potentially be associated to information accessibility and availability constructs, as the right amount of information was available when needed (f,n,a,b,c,d), as well as it was easy to access (f,n), understand (f,n,a,b,c,d) and update (f,n). There was also a decentralisation of information and decision making when using these tools, enabling stakeholders to use them independently with increasing autonomy.

The metrics displayed at the performance dashboard 1 (e) were fed with information collected from the activity's tracker (f), also presenting a large number of stakeholders involved, such as project manager, team leaders, BIM manager and client. However, when compared to other tools, this was the least integrated one, as it was developed with team members input information through the activity tracker tool, although only the project manager incorporated and used it effectively to analyse the performance. There was a lack of routine for data analysis during the meetings, and the performance dashboard 1 did not fully support design planning and control in weekly and monthly meetings. It was only used occasionally. Taking that into account, the information in the performance dashboard 1 was not always available to team leaders and the use of the tool was not decentralised through the different meetings and team members.

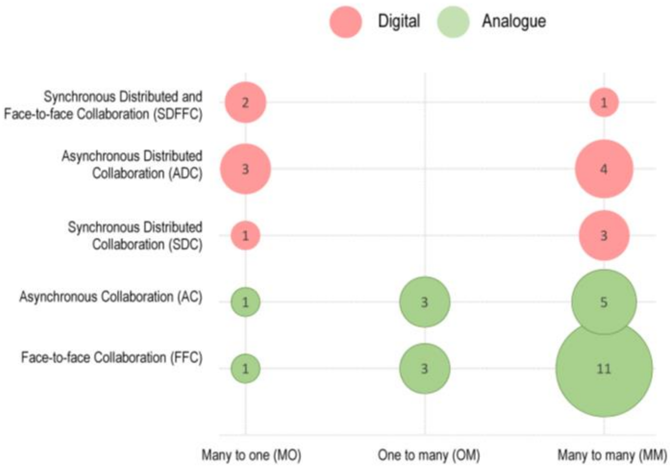
The Navisworks tool also engaged different stakeholders and disciplines within weekly coordination meetings. The tool was fed with information from team members and BIM manager. However, the process of information sharing was not fully integrated, i.e. each discipline sent individual models to the BIM manager, who created and shared the federated model with all disciplines to guide the discussion during the coordination meetings. The federated model was available to all disciplines and each of them was able to incorporate the changes in their own models. Thus, it is classified as 'one-to-many' and 'many-to-one', considering the clash detection cycle is fragmented into two key moments. The clash detection cycle was repeated until clash tolerances (criteria) were met. Nevertheless, the federated model was used by many stakeholders and the information, e.g. comments, sent by all disciplines were available to all of them through the shared model during a specific clash detection cycle. So, this specific part of the process can be classified as 'many-to-many'.

The process of information transfer with the GIS coordination tool (q) was very similar to the previous one, however, the input of information was fed by the project manager and team leaders. The process was also classified as a fragmented way of sharing information, considering there was a need of converting the information from spreadsheets into GIS. The tool started to be implemented within the meetings at the end of the empirical study, as a support to decision making at a tactical level of coordination, being available to stakeholders, as team leaders, client and project manager. This tool was classified as 'many-to-one'.

In summary, most of the digital VM tools were used at some points in time for specific activities. The tools usually supported collaboration of stakeholders in meetings, but they were implemented mostly at the tactical and operational level between disciplines, without enough reflection on the team member needs at operational levels inside of each discipline. In fact, the company started to encourage the use of VM digital tools at the team level recently, with the aim of improving the connections to other managerial levels. The collaborative visualisation emphasised the 'visualisation' and 'exploration' levels, defined by Isenberg et al. (2011), as there was a level of engagement, the stakeholders shared the same visualisation tool interactively and they were able to create and share new information. However, the category of 'sharing' was still limited, as there were difficulties for many people in creating, uploading and sharing new data sets and visualizations.

Figure 109 presents the **level of digitalisation** (digital and analogue), **communication approaches** (FFC, AC, SDC, ADC, SDFFC) **and VM practices integration** (many-to-one, one-to-many and many-to-many). The digital VM tools were usually adopted at (i) synchronous distributed collaboration (SDC), (ii) asynchronous collaboration (AC), and (iii) synchronous distributed and face-to-face collaboration (SDFFC), whereas the analogue tools were mostly used at (i) asynchronous collaboration (AC) and (ii) face-to-face collaboration. The digital VM tools were mostly described by many-to-one and many-to-many interactions between its users. The analogue VM tools were mostly categorised as many-to-many, also presenting some tools classified as one-to-many.

Figure 109 – Number of VM tools for each level of digitalisation, communication approach and VM practice integration.



Source: the author.

The analogue VM tools still tend to support a greater collaboration through face-to-face communication than the digital tools do as represented in Figure 109. As a consequence, the implementation of digital VM tools through face-to-face communication emerged as a potential approach through open interviews, as a way to support collaboration and integration between the different stakeholders, e.g. screens in a traditional room with digital planning and face-to-face communication. In this approach, digital tools support new ways of information transfer through a greater information availability and traceability, extending the existing capabilities, but still considering the traditional approaches for collaboration and communication. However, characteristics related to the ludic aspect of analogue tools, e.g. type of coding (colour, shape, texture, symbols), were not considered and emphasised during the analysis of digital VM tools, and represent a limitation to this investigation.

The main impacts related to the adoption of the types of VM tools in design management were identified through qualitative analysis of the interviews, and direct and participant observations of project meetings. The main impacts of types A and B were related to the **improvement of communication, support for decision-making and transparency**. The ease to use, accessibility and transparency aspects of digital tools for the design management can be very effective in the decision-making process, also supporting the documentation of decisions in the very early design phase, as described by Den Otter and Prins

(2002). The impacts and challenges in the information flow can also be associated to low transparency and restricted communication, as pointed out by Dallasega, Rauch and Linder (2018).

Figure 110 – Relationship between VM tools and impacts.

	Decision-making I1	Transparency I2	Communication I3	Collaboration I4	Discipline I5	Complexity Reduction I6
Collaborative board with milestones and deliverables (a – EES 1)	x	x	x	x	x	x
Collaborative board with milestones and deliverables (a – EES 2)	x	x	x	x	x	-
Whiteboards (b/c/d)	x	x	x	x	x	x
Performance dashboard 1 (e)	x		x	-	-	
Activity tracker (f)	x	x	x	x	x	x
Activity tracker with weekly lookahead (n)	x	x	x	x	x	x
Performance dashboards 2 (o)	x	x	-	x	x	
Navisworks for clash detection, quality control and control of changes (p)	x	x	x	x	x	-
GIS for coordination (q)	x	x	x	-	-	x

Source: the author.

The adoption of both digital and analogue VM tools (i) enabled collaborative discussions and agreements in key decision-making points; (ii) enabled focused meetings; (iii) helped in structuring meetings and discussions; (iv) increased the visibility of design information for all disciplines; (v) encouraged independent use of the tool, supporting team autonomy.

Digital VM tools related to status dashboards, performance dashboards, and product models simplified the task of planning, control and coordination, facilitating progress reporting; and anticipated problems as the data stored can be easily found and selected.

The **performance dashboard** allowed the availability of context-relevant data, e.g. metrics according each discipline or project, enabling the track of progress and store of accurate data, whereas the **activity tracker** (i) facilitated design management changes and instant feedback of those changes to all stakeholders involved; (ii) provided effective transfer of information between distributed design teams from different disciplines and companies, as well as with the client, through an early and regular share of information during the design process; (iii) provided accurate, updated and real-time information of the design progress to all stakeholders; and (iv) supported the decentralisation of decision-making through easy access to information by all stakeholders.

Analogue VM tools, such as collaborative planning boards with milestones and deliverables as well as whiteboards, (i) prompted people to easily identify the interdependencies of work and responsibilities as they were located in the same place and had face-to-face interactions; (ii) encouraged team engagement and ownership of both work and tool through the simplicity of analogue VM tools; (iii) encouraged informal and quick discussions through face-to-face interactions.

6 VM REQUIREMENTS, CONCEPT MAP AND GUIDELINES FOR VISUAL MANAGEMENT IN DESIGN MANAGEMENT

This chapter is divided into three main sections. Section 6.1 describes the VM requirements and concept map for design management. Section 6.2 describes the guidelines for Visual Management implementation in design management. Section 6.3 presents the evaluation of the artefact, based on the constructs described in the research method.

6.1 VM REQUIREMENTS FOR DESIGN MANAGEMENT AND CONCEPT MAP

The first key contribution of this work is the identification of a set of requirements for the implementation and evaluation of VM tools in design management, considering the context of digitalization. **Error! Not a valid bookmark self-reference.** presents the set of constructs used to categorise these requirements, the main references used and their definition. The definition of each requirement described below was relevant to the present research context, i.e. design management and digitalisation, however, they are not only limited to those ones. These are:

(i) Simplicity (R1): it is concerned with how easy it is to understand the objective of the tool and how to use it;

(ii) Information standardisation (R2): it is related to the accuracy of the information delivery, making it easy to define priorities;

(iii) Information availability (R3): it is related to making updated information available, in the right amount, and in real time;

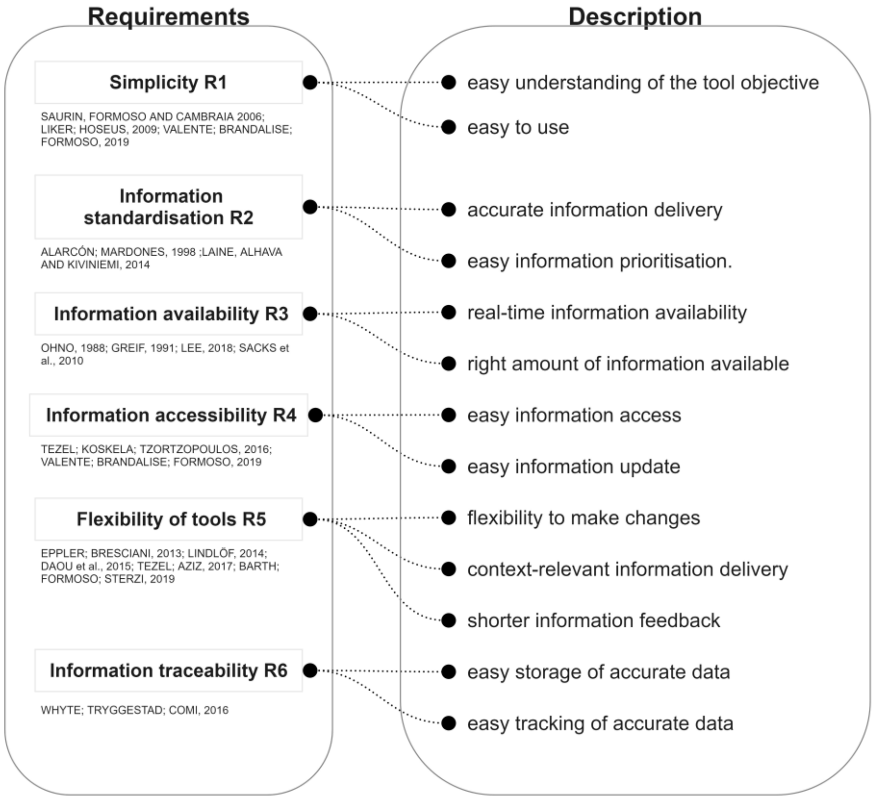
(iv) Information accessibility (R4): it considers how easy it is to access and update information, as well as it can support shorter time feedback;

(v) Flexibility (R5): it is related to how easy it is to make changes, mobility, and shorter time for updated feedback, in order to have context-relevant information delivery;

(vi) Information traceability (R6): it is associated to the easy storage and tracking of accurate data.

The proposed requirements represent a contribution to the adoption of digital VM tools in design management, and the relevance is related to the characterisation of VM tools in design processes, considering traditional and new constructs, to evaluate, develop and implement digital tools in the analysed context.

Figure 111 – VM requirements.

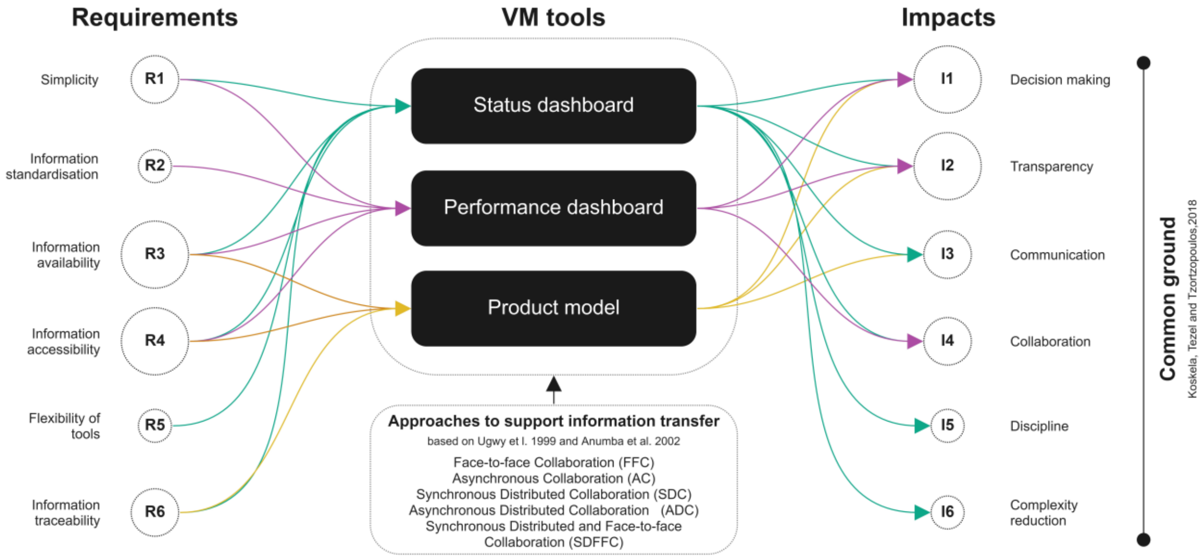


Source: the author.

Additionally, to the identification of the requirements, different types of VM tools, i.e. Type A, B and C, were identified in this investigation, describing the nature of VM tools for supporting the design management process. Type A supports design planning and control, related to the process design, while Type B is associated to product design, emphasising the design coordination. Finally, type C supports the continuous improvement and learning. However, Type C was not explored in this investigation, due to limitations in the empirical study, representing an opportunity for future studies. Status dashboard (e.g. activity tracker) and performance dashboard were identified as the main types of tools associated to Type A, whereas product models (e.g. BIM and GIS models) were associated with type B.

Figure 112 presents the main requirements for each type of VM tool, and also their most important impacts in design management. These were categorised as: decision making (I1), transparency (I2), communication (I3), collaboration between the stakeholders (I4), discipline (I5) and complexity reduction (I6). Some of the concepts were also identified in the literature, such as benefits related to VM adoption (KLOTZ, 2008; TEZEL, 2011; BRANDALISE, 2018; VALENTE; BRANDALISE; FORMOSO, 2019).

Figure 112 – Relationship between VM tools, requirements and impacts.



Source: the author.

Decision making (I1) is associated with making effective choices by identifying the options, organising the information, and defining alternative solutions in a simplified approach with the support of VM tools. **Transparency** (I2) consists of making the production process comprehensible and observable to all stakeholders by using public display of information, measurements, and physical means (KOSKELA, 2000), communicating with all participants (FORMOSO; SANTOS; POWELL, 2002). VM in design management can support process transparency, through design planning and control VM tools, and product transparency, through design coordination VM tools, as suggested by Klotz (2008). Effective **communication** (I3) through the implementation of VM tools can integrate different stakeholders, increasing the accessibility of information and team's information processing capability. Collaboration (I4) aims to engage different stakeholders in the same problem through iterative processes, shared responsibilities, risks and rewards. **Discipline** (I5) is related to the conformance in relation to procedures, so that the employees are able to develop intuitive correctness without being dependent on another individual (TEZEL, 2011), allowing more autonomy to use the tools. Information **complexity reduction** (I6) is essential to simplify and reflect organisational realities in the complex environment (TEZEL, 2011) for people to utilise in daily transactions and interactions.

The share of information through different types of VM tools and the creation of a common ground enables accurate and consistent information available to all parties involved. Such tools can potentially improve the communication, collaboration and decision making, which supports the development a better design development, as described by Koskela, Tezel and Tzortzopoulos (2018). The adoption of visual tools for design management may also increase the engagement and autonomy of users, as a result of an improved decision-making process and increased transparency between stakeholders.

The approaches to support the transfer of information considered as relevant in the implementation of digital VM tools are: synchronous distributed collaboration (SDC), and asynchronous distributed collaboration (ADC). This research also pointed out the possibility of having a mixed approach, adopted in the empirical study, which is defined as synchronous distributed and face-to-face collaboration (SDFFC). It considers interactions at the same time, in the same place and different places, allowing the users to be co-located or distributed to use the VM tool in the same moment.

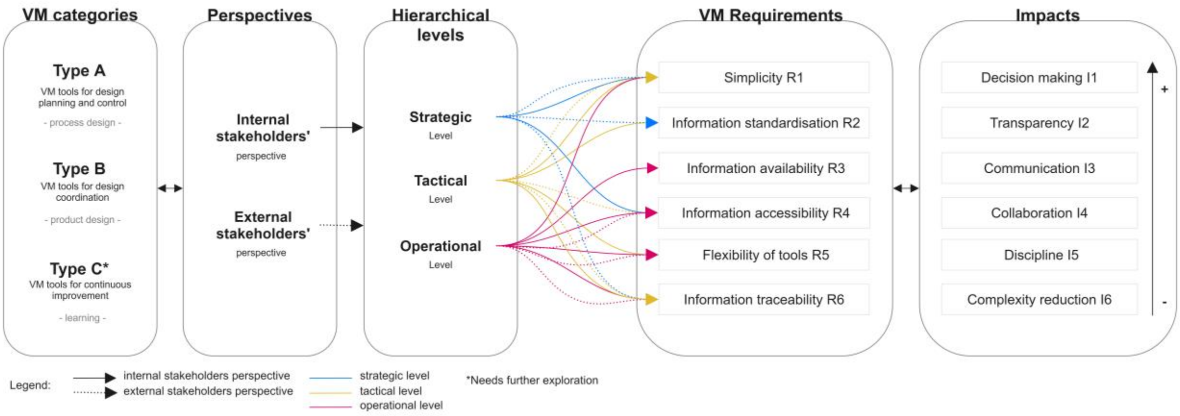
Face-to-face and asynchronous collaboration (FFC and AC) approaches are also essential when considering the implementation of hybrid approaches of VM, e.g. digital visual tools supporting face-to-face interactions or display in traditional big rooms (projectors in a traditional room with digital planning as identified within the empirical study). The hybrid implementation of digital VM through traditional approaches of communication (i.e. face-to-face and asynchronous collaboration) emerged as an approach that can potentially support the collaboration and integration between the different parts involved in the processes. The digital tools do not replace existing tools, as mentioned by Murata (2018), but they have the potential to support new ways of information transfer across organisational levels, extending the existing capabilities, as explored in this research study.

Considering the types of VM tools, VM requirements and impacts presented above, a concept map is proposed to integrate them into different design management hierarchical levels. The map represents the digital visual management characteristics required to support the design process from different perspectives. It is associated with the requirements of VM tools analysed and proposed in this work, understanding and characterising digital VM tools according to a set of constructs and analysing the VM work cycles, i.e. visual and non-visual work. In fact, some findings of this investigation provided initial contributions that could be useful to support the VM implementation in digital environments.

The concept map explores the connection of a set of VM categories described previously according to each hierarchical level (Figure 113), characterising the VM tools within the design management context. The understanding of the essential VM requirements needed for the different hierarchical levels within an organisation is not explicit in the literature, and this understanding can potentially contribute to the improvement of VM application and evaluation in design, however, there is no empirical evidence.

In addition to the design management hierarchical levels, the model also considers two different perspectives: internal and external stakeholder's perspective. External stakeholders are considerably involved in the design process and usually get involved in the adoption of VM tools during the process, mostly in high level decisions. Both perspectives have connections at all levels, presenting different requirements according to the involvement of the stakeholders in the process.

Figure 113 – Concept map connecting different VM constructs related to design management systems.



Source: the author.

The VM types implemented at **operational level** are described by a large number of characteristics, i.e. simplicity of functioning, information accessibility and availability, flexibility and traceability of information. The flexibility of tools is mostly related to the fact that actions should change faster to adapt to the deadlines defined in the tactical and strategic level, usually considering a weekly basis of capture, analysis and processing of information. The external stakeholders' perspective emphasises information accessibility, flexibility and traceability, which can enable them to easily access the information in different moments of the process, as well as to track the progress of specific teams when required.

The requirements related to information standardisation, simplicity and flexibility characterise the VM implementation at a **tactical level**, aiming to support phase scheduling and look-ahead meetings. The cycles of planning, control and coordination of design process at the tactical level are shorter than in production, requiring simple and flexible VM tools as a way to adapt and change as needed throughout the management process; and the information standardisation can also support that. The external stakeholders' perspective focuses on simplicity, accessibility and traceability, allowing them to understand, access and track the medium-term planning.

The VM tools implemented at **strategic level** are characterised mostly by simplicity and information accessibility for the internal stakeholders. Considering the update of the master planning is more scattered, requiring the simplicity to use the tools and, consequently, to understand the information, as well as requiring easy information access. The simplicity is mostly required as usually there is an excessive level of detail in long-term plans, making them difficult to be updated. The adoption of the tools by external users can be facilitated with information standardisation, information traceability, and simplicity of functioning. The client, contractor or subcontracted companies can easily understand the right information through the standardisation of information, avoiding misunderstandings and preventing loss of time to interpret information, as they can easily use and understand the objective of the tool, as well as they can track the main decisions.

Digital VM enhance some requirements from analogue VM, such as simplicity, and information standardisation, and also present new ones. The new requirements emphasised by digital VM are: flexibility of tools, information traceability, information accessibility and availability. The digital VM tools are characterised by different degrees of flexibility, which can potentially allow easy changes and shorter information feedback, for example. The traceability of information is essential to the context of design management, and it is highlighted in the literature a lack of information traceability in the analogue VM tools. The difference between information accessibility and availability is also emphasised in the digital VM tools, in which availability is related to the real-time availability and the right amount of information available, while the accessibility refers to easy access and update. For instance, information tends to be available through a real-time availability in digital tools, however, the stakeholders still face some difficulties in accessing the tools, e.g. technical issues.

Some of the requirements are still a challenge to achieve even though they are necessary. Specific tools for design coordination, planning, and control still present issues regarding their simplicity, the excess of information and the lack of relevant information prioritisation. The effective use of information and the selection of the right information for the right purpose is also considered as a challenge. Challenges related to the flow of information between those involved in the processes can be related to low transparency, inadequate information transfer and restricted communication.

6.2 GUIDELINES FOR VM IMPLEMENTATION IN DESIGN MANAGEMENT

The guidelines are based on three different perspectives for the implementation of VM tools in design management, which are: the stakeholders (people), the management processes, and technologies

(**Error! Reference source not found.**). The guidelines address general recommendations for VM implementation in design management (section 6.2.1), as well as specific recommendations of VM implementation within a digital environment (section 6.2.2), facilitating and supporting their adoption. The first section explores existing guidelines related to the traditional VM approach which can also be implemented in digital contexts, whereas the second section investigates specific guidelines for digital contexts. The understanding of the process, user's needs and the VM tools integration into collaborative practices prior to the definition of the tool's interfaces and attributes is important, i.e. considering both visual and nonvisual work and corroborating suggestions made in the Visual Management literature (NICOLINI, 2007; VALENTE, 2017).

Figure 114 – Three perspectives adopted for the guidelines.

Perspectives	Description
People	To encourage and support people development and training
Management processes	Enhancement of design management levels integration and improvement of cross-discipline collaboration
Technologies (VM tools)	Gradual introduction of technologies and visual management tools into management processes

Source: the author.

6.2.1 Guidelines for VM implementation in design management

Involving the workforce in the development and implementation of VM tools.

The engagement of all stakeholders across organisational levels is needed to enable the successful implementation of the proposed guidelines, encouraging an initial effort from high-level managers in the adoption of digital tools and avoiding a completely top-down implementation. The commitment from top managers plays a key role in the implementation of VM tools, as suggested by Tezel (2011). The initial effort from high-level members to structure and implement the tools is even more important when related to digital technologies, as they demand higher financial investments with technology implementation and training. Besides that, it was considered as one of the important factors for the successful implementation of new digital VM tools in this research work. As soon as it is established, people have more initiative to adapt the tool as needed and incorporate it into their work routines.

Preparing stakeholders and create a routine for the implementation of digital approaches.

The preparation of users involves raising their awareness about new management processes and the use of VM tools. A comprehensive training plan for managers and designers may be necessary, explaining the advantages of using the tools. It is also necessary to motivate them in order to avoid resistance to change, and to monitor progress through close supervision (BARTH, 2007; TEZEL, 2011; BARTH;

FORMOSO; STERZI, 2019). In the empirical studies, the adoption of an implementation routine contributes to achieve consistency in using VM tools. A training program on the Lean Philosophy was also explored as an approach to increase the team members' understanding and engagement regarding both the design planning and control system and the VM tools adopted.

Mitigating issues related to the complexity through a consistent planning and control routine.

A consistent and well-defined managerial process makes it easier to implement VM tools at different hierarchical levels, i.e. well-defined work packages and a clear work sequence provide an understanding of interdependences between disciplines. Tools and responsibilities clearly defined for each design planning, control and coordination meeting can support a clear definition of each meeting's inputs and outputs, who needs to attend and their frequency, potentially increasing the stakeholder's engagement with the meetings and avoiding overlap of meetings. A lack of those definitions was identified in the embedded empirical study 2, which was characterised as an opportunity to improve.

Nonetheless, the implementation of VM tools in all organisational levels also supports the definition of managerial processes. There is a need to introduce VM tools at the team level and connect them into the weekly and monthly meetings to encourage a greater commitment of team members with the use of tools. This practice is suggested by Brandalise (2018) and Tezel, Koskela and Tzortzopoulos (2017), and was considered as one of the important aspects for the successful engagement of teams in the VM implementation, in the embedded empirical study 3. It is supported by transparency, which can promote collaboration and allow decision making in all organisational levels. It may contribute to increase the autonomy and engagement of employees and to create more consistent results. The reduction of design duration can also be potentially achieved by increasing the decentralisation of information and considering more effective interactions, as observed through the availability and flexibility of information in digital tools.

Supporting the early involvement of external stakeholders.

The early involvement of the external stakeholders, i.e. clients, contractors, and other companies, in the meetings and VM tools allows the identification of requirements in the early stages of the design process, avoiding later changes in the project. The early involvement can be facilitated by simplicity, flexibility, information traceability, and standardisation of the VM tools. The VM tools can support an easy access and information availability, through information standardisation. It was found that traceability of decision making for external stakeholders is also essential and this requirement is facilitated through digital VM tools. It enables a greater process and product transparency, as there is a better understanding of the processes by the client, as suggested by Dallasega, Rauch and Linder (2018). Increasing stakeholders involvement in design management can potentially reduce resistance in the adoption of the Last Planner system and VM tools, increasing self-management, as suggested by Tezel (2011).

6.2.2 Guidelines for VM implementation in design management within digital environment

Prioritising the right information for each organisational level.

The overload of information is described by Murata (2018) as an issue associated with the waste of visualisation. The excess of information and unnecessary detail in VM tools can make it difficult to update regularly. It can also result in the overlap of information in meetings and VM tools, which can result in wasting of time and lack of stakeholder's engagement with those meetings. Digital tools sometimes present an excess of information combined with a lack of information prioritisation. The studies carried out throughout this investigation emphasised the challenges related to the effective use of information and the selection of the right information for the right purpose, considering the tool for design coordination, planning, and control. There is a potential to better select the information with emphasis on important data for each organisational level.

Creating formalised VM systems.

The information accessibility and availability of digital tools support the creation, implementation, and adoption of formalised VM systems. It may contribute to improve team engagement in decision making by an easy visualisation of accurate information within different management levels by geographically distributed stakeholders. The implementation of digital tools is encouraged as a way to improve collaboration between stakeholders, considering teams of big companies tend to be distributed in different places and offices.

Encouraging the continuous improvement of the digital visual tools.

The continuous improvement within the creation and implementation of those digital tools emerged as an important aspect during this investigation, and it presents the potential to support a greater stakeholder's engagement in their use, as the interfaces are easily customisable, developed and improved reflecting the user's needs during the use. In addition to that, the flexibility of tools is important to adapt them to users' needs, enabling a greater trust and autonomy in using the VM during design processes. Visual tools can change users' engagement with the work, enabling an increase of stakeholder's morale and motivation (SANTOS, 1999).

Encouraging early and regular information transfer between stakeholders through digital tools

Information transfer can be affected by the lack of coordination within the systems, which can result in project overruns (EASTMAN et al., 2008), and the lack of right information available at critical points can also result in an extended design process (ZIRGER; HARTLEY, 1994). It was found that encouraging information transfer between teams is essential to design processes, supporting communication throughout the management hierarchical levels during collaborative processes and mitigating information complexity. The regular share of information can also allow better engagement of all team members and understand the disciplines' interdependencies. The digital tools also present the potential to coordinate and integrate teams into the process considering team members are based around the world, as observed in the empirical study of this work, which presented good practices related to its implementation.

A digital environment allows new ways of work and communication, providing real-time information, easy access, traceability of information, and better availability of appropriate information visually. The digital VM tools have the potential to assist the dissemination of updated and accurate information through dynamics approaches during the design stages, as observed during the empirical study.

Supporting reliable traceability of information, with effective data storage and processing

The traceability of information is related to the ability to track design decisions and changes throughout the design process, supporting the decision-making process (WHYTE; TRYGGESTAD; COMI, 2016) through efficient communication. The empirical studies carried out in this investigation highlighted that a systematic approach to track and store information with digital VM tools can allow faster feedback of changes, easy capture of updated information, quick improvement cycles and real-time information availability, contributing to anticipating risks and waste due to information accuracy.

6.3 EVALUATION OF THE SOLUTION

This investigation essentially contributed to structuring the understanding of the real problem related to the adoption of visual management and digital tools in design management, playing the role as the first step for future design and implementation of VM in this context. The preliminary evaluation of the VM requirements in terms of the applicability was limited to the simplicity of the structure and definition of the requirements for the users. In general, the fundamental ideas of the requirements were easily understood by the professionals involved in the workshops and discussions. In fact, some of the requirements, e.g., simplicity, standardisation, and flexibility, were often mentioned when assessing the existing design planning and control system and VM practices.

The constructs related to traditional VM are widely discussed in the literature. Thus, the fundamental ideas of the model were easily understood by the professionals, although difficulties were faced throughout the translation of these requirements to the digital environment and the understanding of the new requirements associated to digital VM, mostly related to the relevance of those constructs to VM development and implementation.

The **simplicity** (R1) emerged in the discussion with experts as one of the main requirements for both digital and analogue VM tools. However, it also emerged as a challenge during the interviews with specialists from the company, as there was too much information in digital tools. The overload of information can make it difficult to update in all organisational levels and create issues related to lack of trust of team members in the tool and planning.

Simplicity was also relevant for the company, in order to engage and commit all the internal and external stakeholders with the use of the tool. The company decided to develop a similar interface to the traditional and analogue boards adopted previously by the company, so the users were familiar about how to use it, keeping it simple as the analogue collaborative boards. The simplicity of the tools can directly support a greater autonomy to use the tools. The autonomy also emerged during the discussion with the key members of the company, which were also involved in the development of VM tools in the embedded empirical study 3. The reliance on the team to use and design their own visual management system was essential to increase the ownership, keeping the tools simple.

Information standardisation (R2) was partially evaluated with the key stakeholders and it emerged from insights of the researcher during the direct and participant observations. The standardisation contributed to making documents clear and understandable, delivering accurate information and easily prioritising the information needed for different purposes.

The **availability** (R3) of the right information for the right purpose at the right time was also suggested by the company specialists as an important characteristic of VM tools, as well as a challenge since there was an excess of information combined with a lack of information prioritisation in the use of VM tools. The right amount of information available was facilitated in digital tools with locking and filtering functionalities, in order to guide the user to an easy and simple experience with the tool, allowing the access and update of the right information by the right user only.

The **flexibility** of tools (R5) to make changes was also highlighted by company members as an essential construct at a team level, supporting a greater engagement and commitment, considering tactical and operational managerial processes, consequently, resulting in shorter information feedback. The flexibility of digital dashboards was also pointed out as an important requirement to allow users to easily navigate around the board and access relevant information through diverse devices and interfaces. It was also highlighted that the same digital VM tool can be flexible and support different practices in different levels of detail, creating different interfaces as required.

Issues about the **traceability of information** (R6) and **information accessibility** (R4) in analogue VM tools were pointed out during the discussions, considering that the teams of civil engineering projects tend to be located in different places and offices (or considering that the stakeholders were working from home due to the covid-19 situation), and those concepts were highlighted as an opportunity to improve the communication through the adoption of digital technologies. It was identified that digital VM tools allow an easy way to track and record information, exporting information needed or including comments when required, enabling a track of the design progress through all the process. However, the accessibility of information was also considered a challenge by the stakeholders, as the information available was limited to some users or projects due to confidentiality issues, creating a lack of transparency in the company and creating difficulties to share lessons learnt between the projects.

7 CONCLUSIONS

This final chapter summarizes the main contributions of this work. It also presents suggestions for future studies, in order to expand knowledge about the topic addressed in the present research.

7.1 OVERVIEW OF CONCLUSIONS

This investigation was motivated and framed by an opportunity to explore a practical problem in an infrastructure design and consultancy company (company A). The problems related to design management provided the background of this research. The visual management and digitalisation were chosen as the theoretical background for addressing those problems and the **main research question** of this research work was defined as: "*how can visual management support design management in a digital environment?*". The research was positioned as a design science research, due to the opportunity to interact with a practical problem and develop a solution through incremental learning cycles.

An exploratory study related to the design development of a retrofit building project was carried out, which investigated the integration of visual management with digital technologies, also analysing traditional visual tools implemented as a way to compare the traditional strategies within the digital approach. The main contribution of the exploratory study was related to the initial identification of different types of VM tools, i.e. type A and type B, related to VM tools for design planning and control and VM tools for design coordination.

The main empirical study of this investigation was divided into three embedded empirical studies developed within company A. The solution, research questions and main topics explored were iteratively refined through the studies, initially focusing on VM, digitalisation and design processes, then evolving to design management. It allowed a better understanding of the VM tools adoption in design management considering a complex and digital environment, in which the analysis of both analogue and digital VM tools were essential to better understand the potential benefits and barriers of a digital context. The embedded empirical study 1 emphasised the analysis of the context through a broad perspective of the design process. The embedded empirical study 2, also described as the main study, focused on VM and design management, and it was framed by design planning and control as well as by design coordination process. The embedded empirical study 3 addressed and refined the findings related to design planning and control.

The starting point of the analysis was a general understanding of the design management processes, analysing the VM tools implemented and integrated in collaborative meetings. The meetings were focused on both design planning and control and design coordination activities, considering strategic, tactical and operational levels.

Key contributions of the empirical study can be described as: (i) identification of good practices and opportunities to improve related to Design and Visual Management, which supported the development of the guidelines; and (ii) relevant VM conceptual contributions. The conceptual contributions were: (i) refinement of VM types A and B and identification of a new VM type (type C), which can be considered as a useful classification to describe VM tools in design; (ii) identification of two key categories of VM tools to support type A: status and performance dashboards; (iii) development of a process model for integrated design management and VM types; (iv) refinement of collaboration and communication approaches, proposing a new category and adapting the taxonomy suggested in the literature; (v) set of VM requirements for design management; and (vi) the identification of VM impacts in design management.

The **main objective** of this investigation was ' to *propose a set of VM requirements to support design management within digital contexts'*, and the requirements are considered as the **main research output of this investigation**. The proposed requirements emerged throughout the research process, which was mostly developed from data collected within the empirical study carried out in company A. The identification of constructs in the literature review allowed to stablish the main ICT aspects based on visual management and design management foundations. The literature review also supported a better association between the fragmented topics of visual management, digitalisation and design management.

Despite the limitations of the applicability of the solution, due to the fact that this research work was focused on the problem identification and understanding, the proposed requirements represent a contribution to the adoption of digital VM tools in design management. The relevance is related to the characterisation of VM tools in design processes, considering VM traditional and new constructs, to evaluate, develop and implement digital tools in the analysed context. The constructs identified were classified in six categories of requirements considered relevant to this context: simplicity (R1), information standardisation (R2), information availability (R3), information accessibility (R4), flexibility of tools (R5), information traceability (R6).

This investigation explored different types of VM tools and their impacts in design management. The impacts and benefits of VM tools implementation in design management were identified in this investigation and classified in six categories: decision making (I1), transparency (I2), communication (I3), collaboration between the stakeholders (I4), discipline (I5) and complexity reduction (I6).

The empirical study also explored traditional and virtual approaches for communication and collaboration, adapted from Ugwu et al. (1999) and Anumba et al. (2002), and the taxonomy of integration, proposed by Brandalise (2018). A new classification of collaboration approach was identified and proposed in this investigation to support VM characterisation, which merged two categories proposed by Ugwu et al. (1999) and Anumba et al. (2002): synchronous distributed and face-to-face collaboration (SDFFC), supporting both virtual and face-to-face meetings combined, due to the fact that some stakeholders tend to be based in the same office and some in different offices. The analysis also suggested that digital VM tools usually involve more users than traditional VM tools, which can be classified as: 'one-to-many', 'many-to-one' and 'many-to-many' interactions.

The **first specific objective** was *'to devise a concept map connecting different VM constructs related to design management systems'*. A concept map connecting VM categories, i.e. the types of VM tools, requirements and impacts into all hierarchical levels of design management, was proposed. The map represents the digital visual management characteristics required to support the design process from different perspectives, i.e. internal and external stakeholders' perspective. The understanding of the VM requirements associated with the hierarchical levels is not widely explored in the literature, and this understanding can provide initial contributions that could be useful to support the VM implementation in digital environments.

The **second specific objective** was *'to propose guidelines for the implementation of Visual Management in design management within digital environment'*. The guidelines are mostly focused on guiding the implementation of VM tools in design companies, facilitating and supporting their adoption. The guidelines were developed based on the good practices, benefits and improvement opportunities identifies within the exploratory and empirical studies. The recommendations explored three main aspects related to: (i) stakeholders, encouraging people development and training; (ii) management processes, enhancing design management levels integration and engagement of disciplines in collaborative practices; (iii) technologies, encouraging the gradual introduction of technologies and VM tools into management processes. The understanding of the process, user's needs and the VM tools integration into collaborative practices prior to the definition of the tool's interfaces and attributes is essential, corroborating with the Visual Management existing literature.

The contributions are divided into general guidelines for VM implementation and specific guidelines for VM implementation in design management within digital context. The first section explores existing guidelines related to the traditional VM approach which can also be implemented in digital contexts, whereas the second section investigates specific guidelines for digital contexts.

The general guidelines are: (1) involve the workforce in the development and implementation of VM tools; (2) prepare stakeholders and create a routine for the implementation of digital approaches; (3) mitigate issues related to the complexity through a consistent planning and control routine; (4) support the early involvement of external stakeholders. The guidelines for VM implementation within digital contexts are: (5) prioritise the right information for each organisational level; (6) create formalised VM systems; (7) encourage the continuous improvement of the digital visual tools; (8) encourage early and regular information transfer between stakeholders through digital tools; (9) support reliable traceability of information, with effective data storage and processing.

There are fundamental issues in the literature addressed in this research: a fragmented body of knowledge analysing the implementation of VM in design management and current discussions of its integration with digital technologies in such context. Considering that, the research work adapted the literature from other sectors, such as manufacture and construction industry, in which the VM has a body of knowledge well developed. The digitalisation and VM can provide benefits for the design management process related to: (i) increased team productivity due to the easy access to appropriate and accurate information by geographically distributed teams; (ii) reduction of design management time by increasing the decentralisation of information and considering more effective interactions; (iii) efficient communication and faster feedback related to the ability to track design decisions and changes through a systematic approach during the design; and (iv) greater visibility of activities and design processes, resulting in a greater shared understanding and in stakeholders' engagement and motivation, enabling the team to become more committed to the activities and more autonomous.

7.2 SUGGESTIONS FOR FUTURE RESEARCH

The development of the artefact still requires a greater effort due to the complexity of design management. Further research on the following topics is suggested:

a) Exploration and implementation of the guidelines as well as modelling them into different contexts, in order to evaluate their utility, considering different levels of IT implementation;

b) Sensorial management has not been explored in this investigation, and it represents a potential topic for future investigation;

c) Exploration of the waste related to the potential and real use of digital VM tools;

d) Further exploration of the continuous improvement tools for design management (type C); and

e) Further exploration of the different dimensions of collaboration related with the adoption of digital VM practices.

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APPENDIX A – Semi-structured Interviews Protocols

Appendix A. Key questions used in the semi-structured interviews with employees of Empirical Study

DATA COLLECTION PROTOCOL

01. The project and design management processes

a. Who are the main stakeholders involved in the project and what are their responsibilities? How many people are involved in the project?
b. Please describe the main design stages, highlighting which stage the project currently is at.
c. Please highlight the main design management activities (e.g. regular planning or management meetings)?
d. What are the main critical activities of the design management process?
e. What is the frequency/duration of meetings and who attends each of the meetings?
f. How do you control the completion of design activities?
g. How design information is exchanged between the disciplines at the project? What are the main challenges related to information transfer in your view?

02. Visual management (VM)

a. What do you understand for visual management?
b. Which VM tools are used and how they support the design planning and control process?
c. At which stages of the design process these tools are used, and by whom?
d. How the existing visual management tools were defined and who was involved in the process? Who creates and who uses VM tools and for what?
e. Is there any training available and how easy is it for team members to use them?
f. Does the company apply digital tools, or BIM specifically, more visually, considering visual management practices?

03. Benefits and barriers of VM

a. In your perspective, does the use of digital VM tools influence the communication and visualisation during design management? How and to what extent?
b. What are the perceived benefits and barriers of VM at the project? Advantages and disadvantages related to e.g. communication, reduction of re-work, productivity, quality of design solutions.
c. In your view, how helpful the existing VM tools are?
d. Are the VM tools used in the project easy to understand and use?
e. Which are the main issues related to the adoption of VM tools?