Visual Management in Brazilian Construction Companies: taxonomy and guidelines for implementation

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Abstract

Visual management (VM) is the managerial strategy of consciously integrating visual tools in workspaces with the aim of increasing transparency on construction sites. Several VM tools and approaches that had been originally developed in the manufacturing context were implemented in construction. However, research on the application of VM in construction as a managerial strategy is scarce. This paper aims to investigate and classify the types of visual devices that can be used in construction sites through multiple case studies carried out in nine construction companies actively implementing VM. It also discusses strategies for the implementation of VM in construction. The main contributions of this investigation are: (a) a VM tools taxonomy that can be used to identify VM application opportunities, providing a basis for evaluating the level of VM implementation in construction; and (b) identification of critical factors for the implementation and various features of the VM strategy in construction.

Introduction

Visual management (VM) is widely used in advanced manufacturing plants and has been pointed out as one of the fundamental blocks of the lean production philosophy (Liker and Morgan 2006). According to Galsworth (1997), VM forms a base upon which other improvement approaches are built and, for this reason, can be adopted as one of the key steps at the beginning of improvement programs. A wide range of tools and approaches have been used in visual management, including visual signs, fool-proof devices, removal of visual barriers, and programs for maintaining a clean and orderly workplace (Galsworth 1997; Kattman et al. 2012). As it has happened to other production management core ideas, VM has largely been developed on advances achieved by industrial engineers and managers in a process of trial and error (Koskela 1992).

Although a growing number VM applications in construction has been reported in the literature, research on the implementation of this managerial strategy is relatively scarce. Moreover, implementing VM in construction sites poses additional

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challenges in comparison to manufacturing: (a) construction sites are changing environments where a large number of crews move continuously; (b) the site layout suffers several modifications throughout the project, demanding an intense effort to update and relocate the necessary set of visual devices; (c) construction sites are relatively large places where different crews spread out; and (d) non-removable visual barriers are incorporated into the working environment as the facility is being constructed (Formoso et al. 2002).

This investigation was based on multiple case studies carried out in Brazilian construction companies that had successfully adopted lean production concepts and tools in their projects. The main contributions of the paper are (a) a VM taxonomy that can be used to identify application opportunities, providing a basis for evaluating the level of implementation of VM in construction; and (b) identification of critical factors for the successful implementation of VM.

Visual Management and process transparency

There are different definitions of VM in the literature, highlighting distinct perspectives that have been adopted in its conceptualization. Ho (1993) describes VM as a simple and attractive communication approach, realized by using various devices such as notice boards, slogans, indication lights, cards (e.g. *kanban*) and visual display units. Tomkins and Smith (1998) emphasize the role of VM as a part of performance measurement systems, manifested in the form of a communication and information center for all employees to understand the organization's strategic directions, performance, and results of improvement initiatives.

According to Imai (1997), VM is about making abnormalities visible, stabilizing and improving processes, along with keeping people in contact with the realities of the workplace. Fillingham (2007) suggests designing VM aids so that managers can simply go-and-see what is happening and anticipate future problems. According to Maskell and Kennedy (2007), VM provides information when it is needed in a simple and easy to understand fashion, which in return creates transparency, meaning everyone is working with the same information.

Therefore, process transparency is a major outcome of VM. Formoso et al. (2002:38) defines process transparency as "the ability of a production process (or its parts) to communicate with people". The goal of process transparency is to replace traditional control with self-control (Greif 1991). Transparency can be increased through the removal of waste, reduction of cycle time, using visual signage, displaying process information, appropriate layout, and maintaining visual order (Koskela 2000). However, rendering a work setting completely transparent to the extent of eliminating all privacy areas may have counterproductive effects (Bernstein 2012).

In this research work, VM has been defined as a managerial strategy that attempts to improve organizational performance through connecting and aligning organizational vision, core values, goals and culture with other management systems, work processes, workplace elements, and stakeholders, by means of sensory stimuli (information), which directly address one or more of the human sensory modalities (visual, auditory, tactile, olfactory and gustatory).

Simplicity and attractiveness in sensory communication are the fundamental ideas behind VM (Ohno 1988). These form what has been defined by Greif (1991) as an information field from which people can freely draw information in a self-service fashion, promoting the idea of workplace autonomy and self-management. Such information fields require visual tools to be pervasive in nature and make information readily-available in a quick glance as the integrated elements of a workspace. Therefore, VM is concerned with close-range communication by nature.

In the communication process, the source of information rendered by VM is the space or environment, namely the space (source) to people (recipient) mode of communication (Greif 1991). In fact, space can communicate with people through (a) architectural design (Lawson 2001), (b) physical artefacts embedded into the environment (e.g. a colored line on the wall) (Arthur and Passini 1992), and (c) digitally augmented artifacts, such as an electronic poster on the wall (Beigl et al. 2001). The problem of long-distance communication of information has been largely overcome by information and communication technologies. However, these often create torrents of data and making available the necessary information at close range still remains an important issue (Bilalis et al. 2002).

Two characteristics distinguish information displayed in visual systems from other forms of communication, such as verbal and written: (a) the information is entirely determined ahead of time; and (b) it relies little or none on spoken words (Galsworth 1997). Another distinctive aspect of visual communication is that it is intended for the group, and not just for the individual. In a conventional workplace, most messages are transmitted by specific information channels, such as meetings and memos, whereas in visual factories, an information field is created, extending access to information to a large number of people (Greif 1991).

VM leads to the realization of a visual workplace (Koskela et al. 2007), in which different visual tools and systems can be used to support different managerial efforts, such as performance management (Tomkins and Smith 1998), quality management (Imai 1997), production management (Ohno 1988; Shingo 1989), human resources management (Greif 1991; Suzaki 1993) and workplace management (Hirano 1995). Galsworth (1997) further groups visual tools into four categories, according to the degree of control exerted by each of them:

(a) Visual indicators: information is simply displayed, and compliance or adherence to its content is voluntary (e.g. safety advisory boards);

(b) Visual signals: this kind of visual device first catches the attention and then delivers its message (e.g. sirens of trucks in movement on site);

(c) Visual control: attempts to impact behavior by structuring or building a message directly into the physical environment while putting physical limits in place (e.g. speed bumps);

(d) Visual guarantee: being also known as mistake-proofing or *poka-yoke* device, it is designed to make sure that only the right thing happens (e.g. electronic circuits that prevent the movement of lifts when the door is open).

The design of visual tools frequently exploit different concepts from cognitive ergonomics and human psychology, such as color coding, shape coding, and the *gestalt* law (Hirano 1995; Galsworth 1997; Monden 1998).

Visual Management in Construction

Koskela (1992) proposed six practical approaches for the implementation of process transparency in construction sites: (a) reducing the interdependence between production units; (b) using visual devices to enable immediate recognition of process status; (c) making the process directly observable; (d) incorporating information into the process; (e) keeping a clean and orderly workplace; and (e) rendering invisible attributes visible through measurements. Using these approaches as a reference, Formoso et al. (2002) carried out an exploratory study to identify existing barriers for the implementation of process transparency on construction sites. Those authors suggested that the effectiveness of visual systems greatly depends on whether other core production management principles, such as reducing the share of non-value adding activities, reducing variability, and reducing the cycle time, have been at least minimally applied.

Bust et al. (2008) pointed out the importance of VM on sites that employ immigrant workers, or a workforce that has a low literacy rate. Those authors emphasize the value of using culturally suitable audio or visual displays on sites that do not require full competence of a language, especially for the communication related to health and safety. Heineck et al. (2002) presented a case study which indicated that process transparency can be substantially increased on construction sites by making relatively simple, low cost changes in the site layout and the product design, along with the improvements in working drawings, activity sequencing, and labor relations.

In recent years, a growing number of applications of VM in construction have been reported in the literature, most of which represent attempts to adapt visual tools that were originally devised for manufacturing plants. For instance, some papers describe successful applications of the *kanban* concept for material supply. Arbulu (2009) described the benefits of using *kanban* for managing the supply of a large number of non-task specific materials in a large airport project. Khalfan et al. (2008) reported the use of a *kanban* system to deliver selected products from suppliers and off-site manufacturers on a just-in-time basis. Furthermore, several applications of *kanban* for managing material handling and delivery on site in Brazilian house-building companies have been reported in the literature (Kemmer et al. 2006; Burgos and Costa 2012; Barbosa et al. 2013).

Another VM practice that has been widely disseminated in construction is the 5S housekeeping programs, mostly due to the implementation of quality management programs in this sector since the Nineties (Yang et al. 2004).

Strongly connected to the aim of reducing variability, virtual prototyping, physical prototyping (Saffaro et al. 2006), and first run studies (Ballard and Howell 2003) are VM tools that have contributed to improving project performance in terms of elimination of waste, validation of products by the client, and identification of safety risks.

Another important application area for VM is production planning and control, mostly connected to the Last Planner System (Ballard and Howell 1994). These include the use of *kanban* cards (Jang and Kim 2007), control panels (Viana et al. 2013), performance charts (Bryde and Schulmeister 2012), and collaborative process mapping (Ballard and Howell 2003). More recently, Brady et al. (2012) proposed a collaborative construction planning and control model, which is firmly based on the use of VM.

Visual systems have also been used to support safety management. Construction sites often have safety advisory boards, and in many countries safety regulations require mandatory safety devices, such as guardrails or fool-proof devices for lift doors. Saurin et al. (2008) proposed an innovative role for visual controls, which is to make the boundaries of acceptable behavior explicit, by using a set of visual devices, such as physical barriers, color-coding, and sirens. Hence, there are opportunities for the development of further fool-proof visual systems, since the availability of this type of device is very low, compared to the manufacturing industry (Tommelein 2008; Saurin et al. 2008).

Regarding the use of information and communication technologies, despite the recent advances such as BIM and mobile computing (Sacks et al. 2009; Sacks et al. 2010a,b), augmented construction field visualization (Kamat et al. 2011) and virtual prototyping (Guo et al. 2010), very little has been reported on the use of advanced information technology for supporting VM in construction. In fact, some very effective applications of the *andon* system for construction sites have been devised with the use of relatively unsophisticated technology (Kemmer et al. 2006; Alves et al. 2009).

The discussion presented above indicates that, despite the growing number of papers on VM in construction, none of them has investigated VM as an overarching managerial strategy. Some of the existing studies have a narrow focus, most frequently investigating the applicability of a specific VM tool, such as *kanban*, *andon*, prototyping, and *poka-yoke*. Other studies discuss how to increase process transparency in construction. However, transparency is one of the main outcomes the VM strategy; not the strategy itself. There is little discussion on VM systems that combine different visual tools functioning together for different purposes. Moreover, not much has been reported on the difficulties related to the implementation of VM in construction sites.

According to the literature reviewed and discussed in this section, papers published with examples of VM usually focus on some specific tool (e.g., use of andons, use of kanbans, use of indicators) but fail to address the topic from a broader and systemic perspective as discussed throughout this paper.

Research Method

VM is very much shaped by the context in which it takes place, as well as the perspectives and motivations of the individuals involved. The fact that construction sites are constantly changing environments with a large number of interdependent crews adds complexity to the phenomenon under study. Thus, the research method should be appropriate to help understanding the complexity of production systems within context specific settings. It should also provide the appropriate level of questioning needed to aid understanding. Therefore, the epistemological option for the research is based on the interpretative school of thought and constructive subjectivism (Gray 2004; Saunders et al. 2007). The researchers investigated VM with an emphasis on facts and different approaches in diverse environments in order to reach a broader understanding of how VM is implemented and how it supports the achievement of project results.

The research strategy adopted was exploratory and relied on multiple case studies (Yin 2003), due to the need to investigate the application of VM in real life contexts. In management research, case studies have often been used to study events that are unusual, noteworthy, unfamiliar, or involve change. Furthermore, case studies are frequently employed to explain the implementation of new methods and techniques in organizations (McCutcheon and Meredith 1993). The unit of analysis in this investigation was the VM implementation strategy and its practical means (visual tools) adopted by different companies.

Nine construction companies (general contractors) located in Brazil (three from the city of Porto Alegre and six from the city of Fortaleza) were involved in this research work. The companies were chosen due to the fact that they all had a strong reputation for being advanced in the implementation of lean production concepts and tools, including VM. Companies 1, 2, 6, 7 and 8 were chosen because they had actively engaged in past research initiatives, and had achieved substantial benefits from their lean production implementation efforts. They had also implemented VM successfully on all of their sites, and were generally recognized as benchmarks in their regions by local academics and practitioners. The remaining companies (3, 4, 5, 9) had implemented some visual devices but not in a comprehensive way, and were defined as followers by local academics and practitioners in relation to the first group of companies.

Companies categorized as innovators were the ones that had pioneered the use of visual management tools present in different categories of the taxonomy, and also used the tools in larger numbers. These companies were perceived by local practitioners and academics (who had long-standing relationships with the companies and thus were well-informed) as innovators because of their willingness to try these tools, as well as serving as case studies that analyzed how the tools worked in a construction environment. The followers were companies that waited to see the results obtained from the implementation of VM tools on innovators' sites before they would try on their own sites. Additionally, the companies categorized as followers tended to adopt fewer practices to their sites. As discussed in the VM Taxonomy section, the study validated the local practitioners and academics perception in terms of the adoption of VM by both groups."

Regarding the scope of academic involvement with the companies investigated, some companies simply took part in VM related research projects, and training programs, while others hired academics as consultants to support the implementation of their lean practices. An overview of the companies involved in the case studies is presented in Table 1.

< Table 1 here>

One construction site was visited per company due to financial and time constraints. Multiple sources of evidence were used in each case study, as shown in Table 2 Altogether, five company managers, seven site managers and seven foremen were interviewed. Site observation, and analysis of documents and archives were carried out in all companies. Furthermore, documents related to the past VM efforts carried out in some of those companies, including papers, reports, photos, and presentation slides, were also analyzed,. For instance, Figure 1 shows a photo taken from Company 8's archives, showing the application of the on-site concrete production levelling through a *heijunka* board. In Companies 3, 7, 8 and 9, the data collection protocol was only partially applied due to limitations in the sources of evidence available.

Fig. 1. Visual concrete production leveling example

< Table 2 here>

Data analysis included (a) the purpose of VM; (b) VM tools and their features; (c) how companies capture VM practices for future use; (d) suggestions for implementation at other companies; (e) issues faced by the companies in the implementation of VM; and (d) measurement of VM performance.

Based on the existing data, a taxonomy, which systematically demonstrates the wide range of practices that can be used for VM in construction, was produced. Creating taxonomies is the effort of classifying the studied phenomenon into meaningful groups (Godfray 2002). In operations management, taxonomies have the potential of creating knowledge as the result of a posterior data analysis to obtain stable groups through classification (Bozarth and McDermott 1998; Martin-Pena and Diaz-Garrido 2008).

VM taxonomy

A wide range of VM practices were observed in the case studies. A detailed description of the taxonomy elements was published as an industry report (Tezel et al. 2010) and they are briefly summarized in this section. Fourteen taxonomy elements were proposed, based on (a) their purpose, (b) application methods (i.e. removing visual barriers and standardization), and (c) managerial goals (i.e. production levelling and production control).

Table 3 shows the purpose of each taxonomy element based on the six practical approaches that were proposed by Koskela (1992) for the implementation of process transparency on construction sites. Table 4 presents the application details involved in those elements.

Data analysis indicated that the more innovative companies adopted a larger number and wider variety of VM tools in comparison to the companies classified as followers (see Table 4), confirming their classification suggested by local academics and practitioners. This indicates that the proposed taxonomy can be used as a means to evaluate the degree of VM implementation.

Furthermore, a number of connections between different VM practices were identified in the case studies. For example, a concrete-mix *kanban* card is used on a concrete mixer *heijunka* board; or workers pick up materials from the site inventory, according to the *kanban* cards in their hands, identifying the correct location by looking at the inventory identification sign (visual order).

< Table 3 here>

< Table 4 here>

VM by Removing Visual Barriers

The main principle behind removing visual barriers is to provide extended transparency to people by enabling observability on site (Koskela 1992). On the observed sites, most elements requiring enclosure (e.g. dining areas, lift control rooms, workstations, and material storage zones) were deliberately enclosed by a material that permits transparency (i.e. glass, chain link or welded wires).

VM for Standardized Identification and Localization

The physical site elements (e.g. site inventories or pathways) were standardized in terms of their identification and location by using visual clues, signs, tags, site maps, shadows, and colors. These standardization efforts often included the warehouses through material grouping, ordering and visual material tagging/identifying, as exemplified in Figure 2.

Fig. 2. Site stock material identification

VM in Systematic Site Order (5S)

Systematic housekeeping efforts, widely known as the 5S programs, existed at the companies in the form of site cleaning, order and standardization. The 5S efforts were sustained by using visually attractive communication means (e.g. mascots, signs, 5S boards).

VM in Production Control

Pull production (Ohno 1988) was applied in the production and delivery of various consumables on the construction sites through visual cards. In this system, the necessary amount of material is pulled by the next workstation from the previous workstation (or site warehouse) by exchanging visual cards, often called *kanban*. Along with production, the site stock replenishment (generally for frequently used materials, such as bricks and cement) was also managed by using those cards, as exemplified in Figure 3a.

VM in Production Levelling

Production levelling using visual boards (*heijunka* boards) was identified in the on-site concrete and mortar production. The levelling was achieved by producing the concrete according to the demands of different crews. The demands were managed by exchanging demand or pull cards (Figure 3a) on a *heijunka* board (Figure 3b), which was managed by a trained operator.


SOLICITAÇÃO
DE
ARGAMASSA
VALE 01 TRAÇO
SOLICITANTE

3(a)


SEGURANÇA
OBRIGATÓRIO O
USO DE PROTETOR
AURICULAR

3(b)

Fig. 3. (a) Different kanban cards; (b) heijunka production leveling board

VM in In-Station Quality

Some companies used a mobile or static type of alarming systems called *andon* with the aim of identifying the deviations from standardized construction processes. The green, yellow and red lights on the systems (see Figure 4) indicate respectively that the work proceeds smoothly, help is required from the site manager, or the production stopped on a building floor.

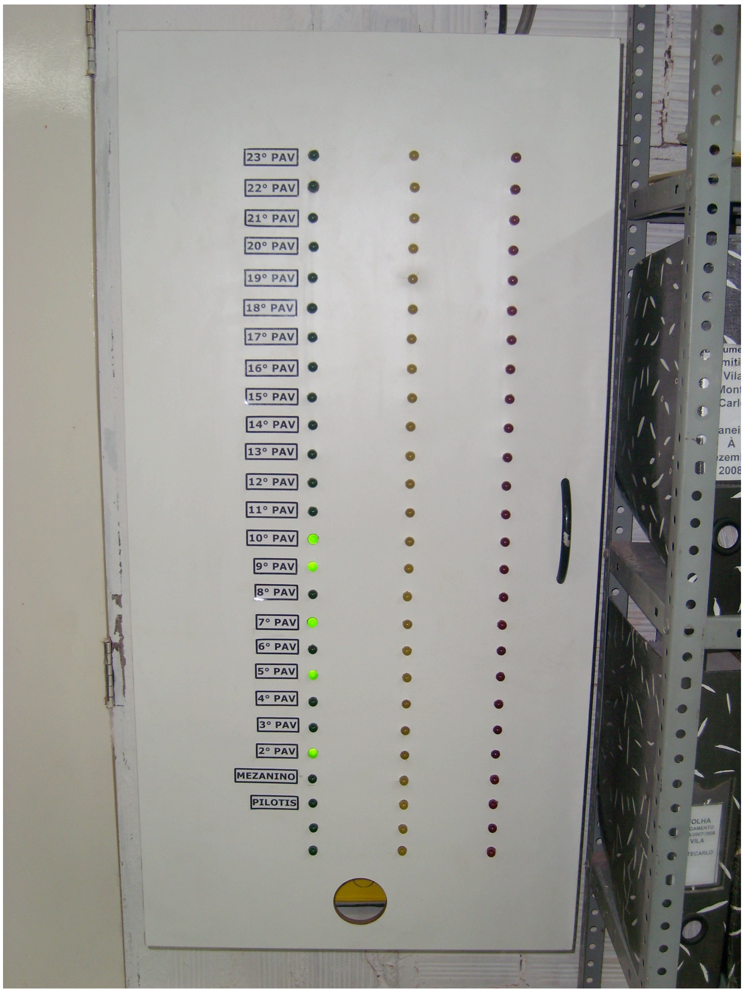

Fig. 4. Static *andon* board for in-station quality

VM in Prototyping and Sampling

Prototyping was used in the form of displaying an example of a part or the whole of the end-product (e.g. a piping system or a complete room), enabling the workforce to visualize the end-product itself. Sampling, the practice of pairing different production elements (material/space or equipment/personnel) by using a real sample of the material and/or equipment in question, was also employed.

VM in Site Signage

Visually attractive and eye-catching signs, posters, sketches, mascots, caricatures were commonly used to support the change management initiatives, internal marketing efforts, to underline best practices, to raise awareness on waste, to emphasize hygiene, health and safety, and to prevent ergonomic problems.

VM in Work Facilitators

This category covers visual aids that were consciously created by management to help the workforce perform their tasks. These devices often serve as a reminder of the standard practices (often technical), providing additional knowledge in the work environment. They should be eye-catching and easy to follow. These visual aids could be designed for anyone on the site, a crew, or a specific worker.

Improvisational VM

Several improvisational visual aids had been integrated spontaneously by the workforce into their work environments, particularly for the quality control purposes. Those visual signs were devised by the workforce and understood by people on the site as a mean of communication. A spontaneous marking on a gypsum wall surface indicating the orientation of an equipment to be installed was a commonplace example.

VM in Performance Management

Different performance metrics to be used by different parties, such as subcontractors, suppliers, and crews, were openly displayed on some sites. However, the degree of adoption of this practice varies depending on the managerial perception about the sensitivity of the information. Some managers find that displaying too much information on performance metrics openly can have detrimental effects on the company-worker or company-subcontractor relationships.

VM in Distributing System Wide Information

System wide information, whether directly related to the production or not, was put on display to enhance transparency, and to raise awareness on the elements of the project system, such as regulations, evaluation of suppliers, company policies, and surveys with the customers.

VM in Mistake Proofing Systems

Mistake proofing efforts were found only in Companies 2 and 7. These were mechanical and electrical devices aiming at standardizing outcomes. The systems consisted of basic mechanical modifications on the material by the site management to guarantee a higher quality production consistently. The small number of fool-proof devices found in the case studies indicates that there is still need for further research and innovation on this practice.

VM in On-Site Prefabrication

There were some site prefabrication efforts carried out with the aim of achieving a higher level of end-product quality, eliminating interdependencies, and expediting a particular construction process. The observed examples include prefabricated electrical junction boxes and mortar preparation units.

Discussion on the implementation of VM

Table 5 presents a cross-case comparison of the VM implementation. Data indicated that VM has been used in those construction sites on a wider scale than generally understood. The interviews demonstrated that in some of the companies there was little awareness on the wide range of VM implementation possibilities. For instance, a manager from Company 8 understood VM solely as displaying performance information and pictures on boards (visual displays).

< Table 5 here>

There was a clear difference in the way visual indicators and visual controls were used. Visual indicators, e.g. performance figures, were mostly used for increasing process transparency on the construction sites, as suggested by Koskela (1992). By contrast, visual controls (e.g. *kanban* cards, *andon* boards) were introduced as an element of a specific system, such as a pull production system for the mortar production, or the in-station quality approach, and were not always perceived by the managers as the outcomes of a conscious VM strategy. This kind of perception may hamper the establishment of a holistic VM strategy and devising original visual tools to support other managerial efforts. In fact, an important distinction between the innovative and follower companies in the application of VM is that in the former the visual practices supported each other as the parts of an integrated system.

Moreover, the implementation effort varied by the type of VM practices. For instance, implementing pull production control through *kanban*, leveling by using *heijunka* boards, the 5S programs, the in-station quality, and the *andon* systems required extensive planning, a certain level of readiness, and stability within the production system. Without sufficient operator training, logistic preparations and site arrangements, those more complex VM practices tend to have no or negative effects in the production system. The 5S for instance, seems easier to implement and is regarded as an initial step to a visual workplace in a manufacturing context (Hirano 1995). However, the interviews revealed that sustaining the 5S on a construction site requires much control and commitment from the workforce. Further, for an *andon* system to function, a support team should be available to go and see where the problems occured and to make improvements on the causes of stoppages (or near stoppages). Finally, the *kanban* system effectiveness requires a reduction on variability in the consumption of materials by reducing process variability and improving planning reliability.

Visual signs, aids, site standardization efforts, performance management, site layout efforts and improvisational VM existed in all of the companies. It seems that those application means are relatively easier to implement, and can be adopted as the initial steps to VM.

Therefore, it is clear that there are different levels of implementation, which can be planned by companies in an orderly sequence. Those levels build upon each other, starting from the more basic site standardization and order to the rather complex visual production levelling and control systems. The mistake-proofing systems were the least used type of the visual tools by the group of companies – only a few basic working examples were found in the case studies. Figure 5 presents the three proposed levels of VM implementation.

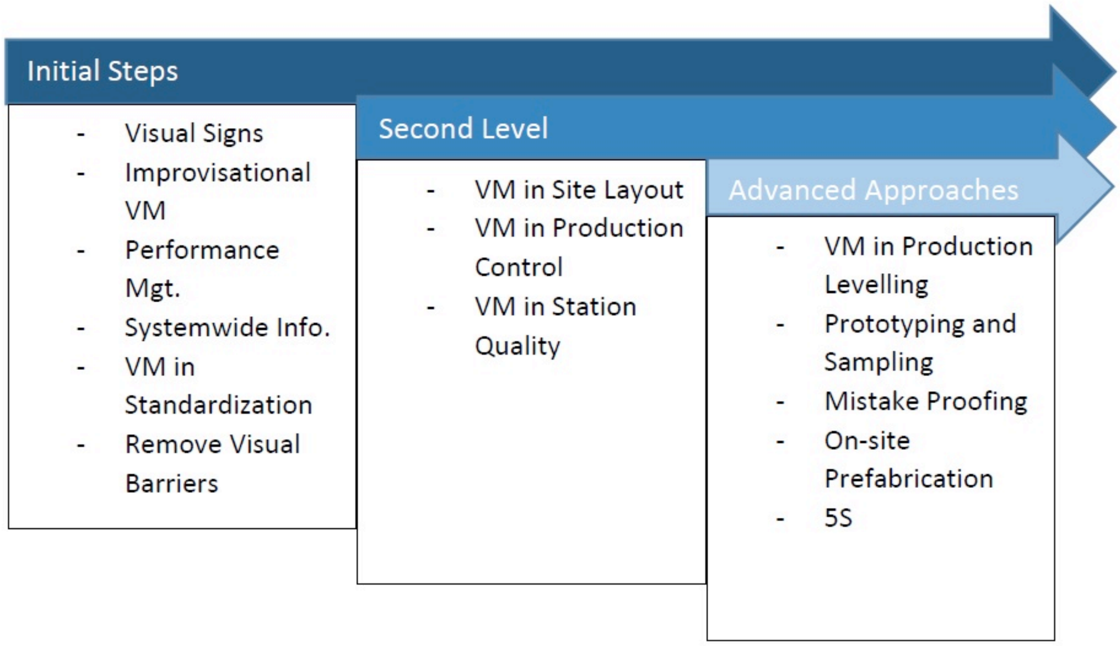

Fig. 5. Levels of VM implementation

Simplicity for both management and workforce was the most frequently mentioned characteristic of visual tools, as seen in Table 5. The other common features were the visual tools being direct, low cost, giving timely information, attractive to the often poorly educated workforce, concise (answering an information need), direct and durable.

In all of the case studies, the implementation of VM adopted a top-to-bottom approach, under the leadership of the technical staff. The foremen had an important role to play as they worked close to the workers. Their active participation and consent were essential for the VM implementation success, since they were usually responsible for the VM tools on the sites. Some site managers also took an active role in the implementation process by capturing and analyzing some improvisational visual communication tools devised by workers, and making them systematic on the whole site. Indeed, one of the essences of VM is actively encouraging workers to design visual tools for their own information needs and to visually share information with other people (Suzaki 1993; Liff and Posey 2004; Galsworth 2005).

Most managers highlighted that training workers is essential for VM implementation (see Table 5). However, the time needed for training and difficulties in achieving changes in working habits were also pointed out as potential barriers. For instance, a manager from Company 7 stated that workers were afraid of making mistakes when using visual tools at the beginning of the implementation. This clearly indicates the need for an appropriate training, a no-blame culture, and workers' engagement to help avoiding the resistance to change.

None of the companies measured the effectiveness of different visual tools or systems. Rather, they measured their productivity, monetary gains or other key performance indicators. The manager of Company 4 explained: "*We simply save money with lean construction and different visual tools*". This comment suggests a practical reasoning behind the implementation.

Some of the companies (mainly the followers) borrowed practices from other companies, while the others (the innovative ones) developed many of the practices themselves. This was partly the result of a close collaboration between the companies, especially the ones from Fortaleza – they shared their lean construction practices with each other openly. Therefore, a sharing culture is important for rapidly disseminating VM. There was also academic involvement in the implementation of VM, which has contributed to creating a higher level of awareness of VM possibilities, and encouraging the companies to establish broader application plans for the future.

No specific software was used to support VM. The managers stated that any IT systems to replace the current VM tools should be financially affordable, easy to use, and resistant to the harsh conditions of construction sites. A manager from Company 7, for instance, emphasized that they had been using the same, simple and economically affordable, vinyl covered *kanban* cards for 5 years. By contrast, developing IT technologies, particularly the ubiquitous computing concept (Weiser 1991), may lead to widespread, ambient-integrated implementation of innovative visual communication systems. Thus, Formoso et al. (2002)'s suggestion of testing new IT systems for increased transparency is still relevant.

The implementation barriers pointed out in the interviews were, in essence, relatively simple to address. The most frequently cited barrier was that training the workforce could take time. Worker resistance to change, high workforce turnover, workers' being afraid of making mistakes when using VM tools, and not properly defining the responsibilities in implementation were other issues pointed out by the interviewees (see Table 5).

The evaluation of the readiness of the construction system for a particular visual tool was also highlighted as critical. The importance of this evaluation was underlined by a manager from Company 5, while explaining their previously failed *kanban* and *andon* system initiatives at the company, which happened due to the ineffectiveness of their production planning and insufficient standardization of material flows.

Conclusions

The VM taxonomy (Table 4) proposed in this paper can be used to increase awareness on the range of VM practices on construction sites. It also indicates where VM tools can be implemented. Moreover, the taxonomy enables the evaluation of the degree of VM implementation on construction sites. Starting from the basic approaches to the more advanced VM concepts, different levels of the VM elements identified at the companies (Figure 5) were also presented as a VM implementation guide. Those findings address a gap in the existing literature, and represent a practical contribution, since the proposed taxonomy may help companies to understand the scope of VM, and to assess the existing degree of implementation.

The VM taxonomy, the comparison of the taxonomy elements, and the levels of VM implementation were proposed based on the Brazilian building construction context. It means that these results are context related, which renders them open for modifications and additions through future research. New visual tools can be devised to address one or more of the process transparency increasing principles outlined in Table 3. There is also room for development and research in the scarcely applied VM tools, such as mistake proofing and on-site prefabrication (Table 4).

A number of important VM application features were identified (Table 5) from a managerial perspective. Those features are important for both VM research and application as they provide interesting information on the VM strategy for construction in general and critical points to pay attention to while implementing VM. A similar kind of study could be executed from workers' point of view to compare the findings.

A synthesis of the critical factors for a successful VM implementation is presented below:

- Realizing that there is a wide-range of VM tools and that VM is more than visual signs or production control (e.g. *kanban*);
- Understanding the theoretical background and interconnection between different VM tools;
- Evaluating the current readiness of the company for an intended VM tool, and preparing the production system if necessary;
- Starting from the initial efforts and moving towards the more advanced applications (Figure 5);
- Obtaining academic support for implementing, maintaining, and developing VM;

- Employing a structured benchmarking process for to properly develop and implement VM tools, instead of simply copying other companies initiatives (Knuf, 2000);
- Avoiding a fully top-down (from the technical staff to the workforce) VM application and making an effort to involve the workforce in the development and implementation of VM;
- Paying attention to the design of a VM tool with respect to ergonomics, human factors engineering, cognitive sciences, and IT opportunities;
- Executing a comprehensive VM training plan that involves highly visual training elements and training by showing. If possible, the workforce turnover should be reduced;
- Gaining the consent of the technical staff by truly convincing them about the benefits of VM;
- Defining clearly the execution methods and responsibilities for different VM tools;
- Monitoring the practical execution of VM, and measuring the VM outcomes;
- Extending the VM effort to other stakeholders (clients, suppliers, community etc).
- Creating mechanisms for improving the VM system.

Several opportunities for further research have also been identified:

- Investigating and actively monitoring a VM implementation process in a construction setting, based on the above mentioned critical points of implementation;
- Comparing the VM taxonomy elements over different parameters (e.g. cost, impact, difficulty etc);
- Studying the proposed taxonomy (Table 4) and levels of VM implementation (Figure 5) in different construction contexts.
- Exploring VM in the whole building lifecycle, including design management and facilities management;
- Investigating the implementation of VM in other types of construction projects, including industrial, highway and power plant constructions.

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Table 1 – Brief description of the companies involved in the case studies

Case studies	Location	The Company	The Project	Classified by Local Academics and Practitioners as
Company 1	Porto Alegre	Employs 300 people. Has operated in residential and commercial building construction for 27 years. In 1998 started implementing the Last Planner System, and in 2002 visual management	20.000 m2 – High rise commercial building for IT companies (US$ 13 million)	Innovative company in VM
Company 2	Porto Alegre	Employs 1200 people. Has operated in residential and commercial building construction for 35 years	27.000 m2 -Two high rise residential buildings (US$ 18 million)	Innovative company in VM
Company 3	Porto Alegre	Has operated in residential and commercial building construction for 30 years	High rise residential building	Follower company in VM
Company 4	Fortaleza	Employs 57 people. Has operated in residential and commercial building construction for 21 years. The lean initiative started around 2002 and gained momentum in 2008	7.000 m2 - High rise residential building (US$ 5 million)	Follower company in VM
Company 5	Fortaleza	Employs 150 people. Has operated in residential and commercial building construction for 28 years. The lean initiative started around 2006	6.000 m2 - High rise residential building (US$ 4 million)	Follower company in VM
Company 6	Fortaleza	Employs 500 people. Has operated in residential and commercial building construction for 25 years. The lean initiative started around 2002	35.000 m2 - Four high rise residential buildings (US$ 16 million)	Innovative company in VM
Company 7	Fortaleza	Has operated in residential and commercial building construction for 16 years. The lean initiative started around 2002	7.750 m2 - High rise residential building (US$ 4 million)	Innovative company in VM
Company 8	Fortaleza	Has operated in residential and commercial building construction for 22 years. The lean initiative gained momentum in 2004	19.00 m2 - High rise residential building (US$ 9 million)	Innovative company in VM
Company 9	Fortaleza	Has operated in residential and commercial building construction for 28 years. The lean initiative started around 2006	13 two-storey residential villas	Follower company in VM

Table 2 - Data Collection Methods Adopted in each Case Company

Case No	Interview with the company manager	Interview with the site manager	Interview with the site foreman	Document analysis (Photos and Field Notes)	Direct observation in construction sites	Archive analysis (Company and Site)	Informal Discussions (Managers and Academics)
1	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3	No	No	No	Yes	Yes	Partially (Site Archives)	Yes
4	Yes	Yes	Yes	Yes	Yes	Yes	Yes
5	Yes	Yes	Yes	Yes	Yes	Yes	Yes
6	Yes	Yes	Yes	Yes	Yes	Yes	Yes
7	No	Yes	Yes	Yes	Yes	Yes	Yes
8	No	Yes	Yes	Partially (No Photos)	Yes	Yes	Yes
9	No	No	No	Yes	Yes	Partially (Site Archives)	Yes

Table 3 – Main Purpose of the VM Taxonomy Elements

VM Element **(after Koskela 1992)**	**Reducing the Interdependencies between Production Units**	**Using Visual Devices to Enable Immediate Recognition of process Status**	**Making the Process Directly Observable through Layout and Signage**	**Incorporating Information into the Process**	**Maintaining a Clean and Orderly Workplace**	**Rendering Invisible Attributes Visible through Measurements**
A. Removing Visual Barriers			**X**			
B. Standardization			**X**			
C. The 5S program					**X**	
D. Production Control		**X**				
E. Production Levelling		**X**				
F. In-Station Quality		**X**				
G. Prototyping and Sampling				**X**		
H. Visual Signs				**X**		
I. Work Facilitators				**X**		
J. Improvisational VM				**X**		
K. Performance Management through VM						**X**
L. Distributing System Wide Information through VM				**X**		
M. Mistake Proofing Systems		**X**				
N. On-Site Prefabrication	**X**					