GUIDELINES FOR THE MANAGEMENT OF COMPLEX SOCIO-TECHNICAL SYSTEMS: AN EXPLORATORY STUDY OF A REFURBISHMENT PROJECT

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ABSTRACT

While lean construction supports the management of complexity, a set of guidelines has not yet been articulated and explicitly linked to complex systems theory. In this study, six guidelines for managing complex socio-technical systems (CSS), proposed by the authors of this paper in an earlier work, are adopted as a basis. The guidelines are: (a) design slack; (b) encourage diversity of perspectives when making decisions; (c) anticipate and monitor the impact of small changes; (d) monitor the gap between guideline and practice; (e) give visibility to processes and outcomes; and (f) create an environment that supports resilience. The applicability of the guidelines to construction is illustrated by an exploratory study of a refurbishment project. Also, as the use of the guidelines only makes sense in a CSS, the investigated project is described according to a set of characteristics of complexity.

KEYWORDS

Complex systems, socio-technical systems, refurbishment.

INTRODUCTION

Lean construction has always been concerned with the complexity of projects (Howell, 1999) and for many years with construction as a complex socio-technical system (CSS). Bertelsen (2003) has been particularly instrumental in promoting complex systems thinking as a lens through which to examine the construction process. Lima, Maia and Neto (2011) argue that complexity theory, unlike the traditional scientific paradigm, is conceptually related to features of the design process in construction. Rooke et al (2008) suggest that the development of complexity thinking in construction can take either of two directions, represented as either the creation of mathematics based models, or the exploration of conceptual issues through the use of metaphors. While Boussabaine (1996) and Boussabaine and Elhag (1999) has been particularly active in the former direction, tending to focus on commercial issues, work in IGLC has tended to follow the latter course and has focused on production.

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The literature on CSS, both that connected to lean construction and to the wider literature, is mostly descriptive (Sheard and Mostashari, 2009). Therefore, guidelines for managing CSS are needed. In this paper, the guidelines identified by Saurin et al. (2013) are adopted as a basis. The applicability of the guidelines to the construction industry is discussed based on the study of a refurbishment project. Also, as the use of the guidelines only makes sense in a CSS, the investigated project is described according to a set of characteristics of complexity.

CHARACTERISTICS OF CSS

There is substantial variation in the number of characteristics of CSS presented in literature as well as in the terms adopted to designate each of them. Saurin and Sosa (2013) compared the characteristics of CSS presented by fifteen studies of two kinds: (a) studies that emphasize complexity in *socio-technical* systems, taking it as a basis to question established management approaches (e.g., Perrow, 1984); and (b) studies that emphasize complexity from an epistemological perspective, suggesting it as an alternative to the so-called Newtonian scientific view (e.g., Cilliers, 1998).

They then grouped the existing characteristics in four categories, which are adopted as a basis in this study: (a) large number of dynamically interacting elements; (b) wide diversity of elements; (c) unanticipated variability; and (d) resilience, which is the systems´ ability to adjust their functioning prior to, during, or following changes and disturbances, so that the system can sustain required operations under both expected and unexpected conditions (Hollnagel et al., 2011). In the study by Saurin and Sosa (2013), the activities of the operators of a control room in an oil refinery were described according to the four categories of characteristics.

It is important to notice that CSS are not the same as complicated systems. According to Dekker et al. (2013) complicated systems are ultimately knowable and controllable, as they afford an exhaustive description. Order in complicated systems is achieved by figuring out one best method to operate them, and there is a clear boundary where the system ends and its environment begins (Dekker et al., 2013). In a CSS, cause and effect are only coherent in retrospect and do not repeat. In these environments, the goal to predict the behavior of systems is difficult if not impossible to achieve (Kurtz and Snowden, 2003).

GUIDELINES FOR THE MANAGEMENT OF CSS

Saurin et al. (2013) identified six guidelines for the management of CSS, based on a literature review of: studies that have used insights from complexity theory for designing CSS (e.g., Dekker, 2011; Hollnagel et al., 2011; Hollnagel and Woods, 2005; Perrow, 1984); reports on practical experiences of using complexity theory insights to support process improvement (e.g., Stroebel et al., 2005; Kernick, 2004); and theoretical discussions on the use of complexity theory to enhance dimensions of organizational design (e.g., Snowden and Boone, 2007). Table 1 summarizes the guidelines.

Table 1. Guidelines for the management of CSS (based on Saurin et al., 2013)

Guidelines	Dimensions of the guidelines
Give visibility to processes and outcomes	Systems should make both problems and complexity visible Visibility should be given to informal work practices, which over time may be considered as part of normal work Privacy may be important for adapting and innovating
Encourage diversity of perspectives when making decisions	Diversity of perspectives may help to tackle uncertainty Agents involved in decision-making should hold complementary skills Some requirements for the implementation of this guideline are: high levels of trust, reduction of power differentials and identification of apt decision-makers
Anticipate and monitor the impact of small changes	Each organization should define what counts as a small change The impacts of small changes may be large in CSS, due to non-linear interactions As small changes happen all the time, they offer frequent opportunities for reflection on practice Small changes may be either non-intentional or intentionally self-initiated by the organization (e.g., through kaizen) as well as originated from external sources (e.g., a client changes its order)
Design slack	Slacks reduces tight-couplings in order to absorb the effects of variability Slack may take a number of forms, such as redundant equipment, underutilized space, excess of labor, generous time margins Slack may have side-effects, such as contributing to maintain problems hidden and disguising small changes
Monitor and understand the gap between prescription and practice	It is impossible for standardized operating procedures to cover all situations, thus inapplicability and need for adaptation should not be surprising Procedures may be of different types (e.g., goal oriented, action-oriented) and, for all types, the gap between them and practice should be monitored
Create an environment that supports resilience	All the previously mentioned guidelines support resilient performance As complexity cannot be fully eliminated, agents must have the skills to adapt to it (i.e., resilience skills) Resilience skills are defined as individual and team skills of any type necessary to fill in the gaps of procedures, in order to maintain safe and efficient operations during both expected and unexpected situations The use of resilience skills requires organizational support, such as granting authority to people self-organize as well as the provision of training

The guidelines presented above are not intended to convey the idea that a CSS can be fully controlled. This would be contrary to the nature of CSS, which are known for their unpredictability. Nevertheless, the impossibility of full control is not exclusive with the objectives of reducing unnecessary complexity, encouraging awareness of the existence of complexity, and providing resources to deal with the inevitable portion of complexity. In fact, the guidelines are consistent with those objectives, as: (a) giving visibility to processes and outcomes makes people aware of complexity, and therefore it supports performance adjustments; (b) encouraging diversity of perspectives tends to reduce uncertainty in decision-making, and therefore it reduces complexity; (c) anticipating and monitoring the impacts of small changes also reduces uncertainty; (d) designing slack reduces interactive complexity, and it absorbs the effects of unanticipated variability, which is a result of complexity; (e) monitoring and understanding the gap between prescription and practice raises awareness of informal work practices, and therefore it reduces uncertainty; and (f) the guideline that stresses the development of resilience skills can be regarded as the most focused on accepting complexity as it is presented, and on attempting to manage it.

Of course, due to the very nature of a CSS, it is possible that unanticipated interactions reduce the intended impact of the guidelines. For instance, a blame culture may hinder the use of the guideline "monitor and understand the gap between prescription and practice", as that monitoring may be used to apply unfair disciplinary actions on workers who do not comply with standardized procedures.

DESCRIPTION OF THE EXPLORATORY STUDY

An exploratory study on the applicability of the guidelines was conducted on the refurbishment of the building of a college in the UK. Refurbishments are well-known for being complex projects (Bryde and Schulmeister, 2012), and thus they are an interesting setting to investigate the use of the guidelines. This research was conducted over two months by two researchers involved in all stages of data collection and analysis. The field study started about at the same time than the start of construction works, when all companies involved in the project were still settling in. Data collection involved: (a) four hours of observations of production planning meetings and safety planning meetings; (b) three hours of observations of site activities; (c) analysis of documents, such as production plans and safety procedures; and (d) five hours of interviews with several stakeholders, such as project manager, site managers, safety advisor, planner, subcontractors, and front-line workers.

A similar script was adopted in all interviews, which had three sections. As an introductory question, the interviewees were asked to talk about the main difficulties they usually face on refurbishments. Next, aiming at gathering data for characterizing the project as a CSS, the interviewees described their activities in terms of technical aspects (e.g., main equipment, production processes) and work organization, stressing issues such as production planning and control routines, safety management and management of procedures. In the last part of the interview, questions were made on the use of each of the six guidelines (e.g., how do you monitor compliance with procedures? Could you present examples of adaptations of procedures? Is there any slack in production plans?) All interviews were transcribed and the reports were analyzed in order to identify characteristics of CSS and examples of the use and potential use of the guidelines.

A REFURBISHMENT PROJECT AS A CSS

The college owner (i.e., the client) hired an architect and a contractor, a large company responsible for projects spread over the UK and other countries. The contractor was in charge of hiring subcontractors, hiring designers from other disciplines (e.g., utilities, structure, etc.) and coordinating the activities between all stakeholders. The only full-time staff of the contractor on the construction site was the project manager, the site manager and their administrative assistants. Other members of the contractor´s staff, such as the safety advisor and the planner, paid regular visits to the site, in order to conduct audits or to participate in meetings. Lean construction was not a familiar concept for the staff, and the contractor had no formal initiative aiming to be lean. The contractor only adopted lean practices if the client, such as government, required their use. The college was located in a two-story building from the 1920´s. Construction works started during Summer´s holidays, in order to facilitate the setup of crews and equipment. Nevertheless, administrative staff was still occupying the building, and after holidays students would return to classes while the refurbishment continued. A peak of 90 front-line workers was expected over the two years of the refurbishment. Over the two months of this study, the peak was about 25 front-line workers.

The characteristic of CSS referred to as "large number of dynamically interacting elements", was present in the project. Indeed, there were several stakeholders, such as: contractor; client; architect; structural designer; and subcontractors of demolition, steel works, utilities, and asbestos removal. Every stakeholder involved a number of workers, either working on the construction site or at the headquarters. Also, some subcontractors had their own subcontractors. In order to facilitate information exchange, each subcontractor and the contractor had individual cabins located close to each other on the construction site. Moreover, as the college was still operative, face-to-face meetings with client´s representatives were fairly easy to be scheduled. It is also worth noting the large number of non-human elements in this CSS, involving the components of an existing building and the equipment and materials employed by workers.

The characteristic of CSS referred to as "wide diversity of elements", was also present in the project. In particular, there was diversity of technical skills, as a result of the specializations of each subcontractor. While there was also a diversity of equipment and materials used by gangs, the full extent of the technical diversity of the existing building was unknown. For instance, the detailed characteristics of the existing structures were discovered only as the construction unfolded. Organizational diversity was a result of the autonomy that each stakeholder had to define its management routines and policies, such as those related to training and planning. Of course, that autonomy decreased as the chain of stakeholders moved from the client to subcontractors. For example, the contractor demanded a tool box safety meeting every morning, involving workers from all subcontractors. Social diversity was not evaluated. This would require data collection on the workforce demographics (e.g., age, marital status, nationality, etc.) and level of expertise.

The two characteristics of CSS discussed above contributed to the existence of unanticipated variability, which is another characteristic of CSS. In particular, unanticipated variability, in the initial phase of this project, was a result of incomplete knowledge about the number, diversity and interfaces of the existing building components. A frequent source of uncertainty, which could result in unanticipated variability, was related to the load bearing nature of walls. A number of interviewees stressed the importance of that subject in their reports, such as: "*when you work on a building of a certain age, you do not really know what to do until you open the building*" (safety advisor); "*there is a lack of continuity in the jobs due to the frequent small surprises, that demand stoppages, re-design and waiting for approvals*" (site manager).

As a compensation for unanticipated variability, the characteristic of CSS referred to as "resilience" was also identified, especially at the individual and team levels. Some reports of the interviewees illustrate the existence and need for resilience: "*it is necessary to adapt procedures all the time*" (safety advisor); "*adaptations of the risk assessment and methods statement (RAMS) are frequent and normal; they present a generic solution* (project manager)". As an example of the need for adjusting performance, the safety advisor reported a case when the process design for demolishing a wall specified that two props would be sufficient. However, during the demolition, when the wall was opened, the crew felt that more props were necessary, and in different positions from those specified in the design. Another example illustrates how individuals devised means for compensating for uncertainty in terms of which tasks should be carried out in the short-term. As the only formal plan was the master plan, many members of staff had their own short-term plans, which often were in their pockets. In fact, the expression "*my look-ahead plan*" was mentioned by the site manager and by two subcontractors´ managers. To make exploratory holes on the walls, in order to get samples of the existing structure, was a strategy cited by the supervisor of the demolition works to identify the need for adjusting plans. According to the supervisor, "*there is no design specifying where to make the exploratory holes, you make this decision on the spot, based on your own experience, and every operative has his own criteria*".

USE OF THE GUIDELINES

The evidence collected indicated the lack of use of the guideline "design slack". For instance, the master plan did not have any slack, regardless of being very detailed. Some of the reports illustrate that point: "*there is no room for problems in this program*" (project manager); "*the assumption of the program is that everything will be perfect*" (site manager). According to the contractor´s planner, a reason for the lack of slack was the fact the client determined the hand-over dates, and there was little or no room for negotiating those dates. The planner also mentioned that, in some projects, the contractor uses a target plan, which establishes a final hand-over date which is a few weeks before the date established in the master plan. The target plan has best case assumptions, and it creates a buffer, since it assumes that delays may happen in the master plan. Regardless of the lack of designed slack in the master plan, it is worth noting that effects of unanticipated variability (e.g., delays in the schedule) can be dealt with by working longer hours and weekends, which is a form of slack of capacity not designed into the system. The lack of a multifunctional and cross-trained workforce, which could also be a resource to deal with variability, was an example of lack of slack in terms of skills. This insight emerged as there was a discussion on which subcontractor should drill the slabs, allowing for the installation of electrical utilities. The responsibility for drilling had not been specified in the contract with the utilities subcontractor, and its workers had no training for drilling. Thus, the need for hiring a new subcontractor just for drilling was raised. Although no final decision had been made until the end of this study, a new subcontractor would add complexity and probably extra costs to the project, due to the new interactions created by job fragmentation.

Some good practices were identified for operationalizing the guideline "give visibility to processes and outcomes". The most noteworthy was the identification of the walls to be demolished, to be extended, and the positions of beams, columns and pad stones (Figure 1). The need for privacy, cited by Bernstein (2012) as important for experimentation and continuous improvement, was naturally favored by the layout of the building. Indeed, gangs formed by a few workers worked within rooms spread over the building, and unlike a new building site (in some phases), they could not be easily observed by other gangs and management.

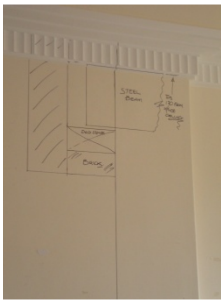

Figure 1: Left: information on the designed positions of the new structures. Right: work order sprayed on the wall.

The previously mentioned incomplete knowledge about the structure was one of the reasons justifying the applicability of the guideline "anticipate and monitor the impacts of small changes". In the words of the steel structures´ contractor, "*the impact of small surprises propagates throughout the supply chain*". On this report, the contractor was thinking on the implications of late changes in the design of the steel structures, due to non-anticipated characteristics of the structure of the building. These changes could imply in the purchase of equipment to install the steel structures, in the allocation of a greater number of workers and in changes in the production schedule of the steel structures manufacturing facilities. Nevertheless, a good practice concerning the anticipation and monitoring of small changes was identified: the need for work permits to use step ladders instead of podiums, even for simple tasks such as changing a bulb. Although it may seem a trivial change, the contractor required the use of the work permit due to the greater safety risks of using step ladders.

As with the previous guidelines, good and bad practices were identified on the use of the guideline "encourage diversity of perspectives when making decisions". On the one hand, a substantial number of meetings used to take place on the construction site, and several of them were followed by a visit to the production areas. Indeed, these meetings fostered exchange of information and supported participative decision making. On the other hand, difficulties of communication among the members of the project management team were pointed out as important drawbacks. According to the contractor´s planner, "*information was not shared freely"*, and according to the supervisor of demolition works, "*sometimes the lines of communication were a bit slow"*. This supervisor was referring to the need for resorting to several stakeholders, in a chain, in order to get the necessary information. In fact, these reports indicate that diversity of stakeholders does not imply diversity of perspectives. Of course, a meeting involving diverse management team members tends to be ineffective in the absence of the right information, at the right time. Moreover, it was observed that the master plan and the RAMS were made by staff who worked away from the front-line. Concerning safety plans, a subcontractor reported that "*(safety) procedures are born on the office, by people who have never done the job"*. A similar situation happened with the master plan, since the contractor had a planner, who had designed the master plan with little inputs from site management.

The use of the guideline "monitor and understand the gap between prescription and practice" was largely informal. In particular, there was no indicator to evaluate the adherence of real work to the RAMS, neither indicators that could show how effective and reliable was the production planning. Observations of the execution of tasks were not guided by checklists or RAMS. The informal use of this guideline was contradictory with the recognition, by all interviewees, of the need for frequently adapting procedures. In fact, it seemed that every individual attempted to learn by doing how to adapt and when to adapt.

A major reason that justifies the need for using the guideline "create an environment that supports resilience" was the inherent technical uncertainty of a refurbishment project. For instance, the limited effectiveness of the pre-construction survey of both the structure and the undercroft (it had much more asbestos than anticipated by the survey), created the need for a number of adjustments in the schedule. Nevertheless, from a broader perspective, it seems that the ineffective application of some guidelines created a portion of unnecessary use of resilience skills, and therefore unnecessary complexity, in the project. Three examples may be cited: (a) the use of generic RAMS, which was not fed back by performance metrics, probably increased the amplitude and frequency of unnecessary adjustments; (b) the lack of hierarchical production planning, which encouraged individuals to devise their own short-term plans; and (c) the lack of systematic training to support performance adjustments. For instance, front-line workers reported that they learned from experience how to identify the best places to drill exploratory holes on the walls as well as which signs they should look for in the existing structure, in order to get knowledge on its integrity and strength. Nevertheless, good examples of supporting resilience skills were identified, such as granting authority to front-line workers to stop working if they felt the activity could not be safely carried out. Another practice that favored resilience was the existence of a project delivery team that had already worked together in other projects, an issue mentioned as relevant by some interviewees. This practice can facilitate communication and the anticipation of actions and decisions of project team members, therefore increasing the precision of performance adjustments.

CONCLUSIONS

This paper illustrated the applicability to construction of six guidelines for the management of CSS, by means of a study of a refurbishment project. On the one hand, the use of lean construction practices, especially Last Planner, could help the investigated contractor to operationalize some guidelines. For instance, Last Planner could have either eliminated or minimized a portion of unnecessary use of resilience skills, by providing formal short-term plans. Also, Last Planner could have supported the use of the guideline "monitor and understand the gap between prescription and practice". This support would be mostly due to the fact that the implementation of the plans would be checked at predefined intervals – e.g., according to Last Planner, the implementation of short-term plans is usually checked either on a weekly or daily basis, and this sets a basis for the calculation of the percentage of plans completed indicator. On the other hand, other situations of lack of use of the guidelines by the contractor are unlikely to be solved only with the support of existing lean construction practices – e.g., the need for training front-line workers to adjust performance, filling in the gaps of standardized procedures.

Due to the exploratory character of this study, opportunities for future research can be identified, such as: (a) to improve the level of detail and scope of the guidelines, based on sources such as additional literature review, surveys with experts in complexity science, and best practices adopted by industry; (b) to develop a protocol for a systematic evaluation of the use of the guidelines on construction projects; (c) to evaluate the use of the guidelines in projects that are committed with lean construction, allowing for an investigation of complementarities and conflicts between it and the guidelines; and (d) to investigate the full extent to which lean construction practices, such as Last Planner, visual management, and Building Information Modeling, may support the use of the guidelines.

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