Ibarra, J.V., Formoso, C.T., Lima, C., Mourão, A., Saggin, A (2016). "Model for integrated production and quality control: implementation and testing using commercial software applications" In: *Proc. 24th Ann. Conf. of the Int'l. Group for Lean Construction*, Boston, MA, USA, pp. 73–82. Available at: <www.iglc.net>.

MODEL FOR INTEGRATED PRODUCTION AND QUALITY CONTROL: IMPLEMENTATION AND TESTING USING COMMERCIAL SOFTWARE APPLICATIONS

José Villamayor Ibarra[1], Carlos Torres Formoso[2], Cicero Lima[3], Alexandre Mourão[4] , Angela Saggin[5]

ABSTRACT

The literature has pointed out that a major problem in quality management systems is the lack of integration with production control. In fact, very often a task is considered to be completed in short-term control, but no quality checking has been performed. The aim of this research work is to propose a model for production control that integrates task completion and quality control, with the support of Information and Communication Technologies (ICT). It is built on a previous version of the model, which was strongly based on the Last Planner System®. Thus, the model was further developed and tested through the use of commercial software packages, which has also enabled the use of BIM for visualizing control data. Besides monitoring quality conformance and the completion of tasks, the model can also be used for measuring some types of waste, such as making-do and unfinished work. Two empirical studies were developed in construction sites located in Brazil. In this paper, some of the results obtained from the instantiation of the model are briefly presented, as well as some suggestions for future research on this topic.

KEYWORDS

Production control, quality control, unfinished work, informal work, making-do.

INTRODUCTION

Despite the advances in production planning and control that have been achieved by the adoption of Lean Production ideas in construction projects, especially by the dissemination of the Last Planner System®, few efforts have been undertaken by the Lean Construction community in order to improve the quality of the final product during site installation (Leão et al. 2014; Rocha 2015).

[1] Civil Engineer, Master Student, Building Innovation Research Unit (NORIE), Federal University of Rio Grande do Sul (UFRGS), Porto Alegre, RS, Brazil, josevillamayor86@gmail.com

[2] Ph.D., Professor, Building Innovation Research Unit (NORIE), Federal University of Rio Grande do Sul (UFRGS), Porto Alegre, RS, Brazil. Phone +55 51 33083518, formoso@ufrgs.br

[3] R&D Manager, C. Rolim Engenharia, Fortaleza, CE, Brazil, cicero@crolim.com.br

[4] Technical Director, C. Rolim Engenharia, Fortaleza, CE, Brazil, alexandre@crolim.com.br

[5] Lean&Green Coordinator, C. Rolim Engenharia, Fortaleza, CE, Brazil, angela@crolim.com.br

Arentsen et al. (1996) stated that it becomes easier to ensure the delivery on schedule and efficient use of resources when quality control is properly integrated with task completion control. Similarly, for Bij and Ekert (1999), production and quality controls in industrial organizations interact in such a way that the good performance of one often influences or inhibits the performance of the other. Moreover, non-completion of tasks with quality checking stems primarily from defective execution of the preceding task, so, if the tasks are inspected by quality control while they are being executed, the defects are corrected in time, preventing propagation of the problems to the subsequent tasks (Fireman et al. 2013).

According to Akinci et al. (2006), the approaches for quality control on construction sites are not as effective as they should be in identifying defects early in the construction process. As a result, defects can go undetected until later construction or even maintenance phases (Akinci et al. 2006). Ballard (2000) states that quality control is normally invoked as a separate control mechanism from production. In this regard, previous research studies have suggested mechanisms for integrating production and quality control (Fireman et al. 2013; Sukster 2005).

Additionally, Leão et al. (2014) proposed a process and a data model to support future IT software development for assessing task completion and quality conformance. The same authors concluded that the integration between production and quality control is considered a means to reduce the incidence of informal packages and waste by making-do. However, in order to facilitate that integration, information technologies are necessary for processing the large amounts of data generated on-site and due to the need for synchronization of planning and control activities.

The aim of this research work is to propose a model that integrates production and quality control, which is strongly based on the Last Planner System® (LPS). It is built on previous versions of the model (Leão et al. 2014; Rocha 2015). This model was further developed and tested through the use of commercial software packages, which have also enabled the use of BIM for visualizing control data. Besides monitoring quality conformance and the completion of tasks, the model can also be used for measuring some types of waste, such as making-do and unfinished work.

INTEGRATED PRODUCTION AND QUALITY CONTROL

PROACTIVE CONTROLS AND WASTE ON-SITE MONITORING

Ballard (2000) states that a major weakness of traditional project controlling methods is the fact that projects may exhibit budget productivity and be on the earnings plan, but not be doing the right work in the right way at the right time. Although things appear to be on track, work is being produced that does not conform to process or product quality requirements (e.g., out of sequence).

Sukster (2005) proposed a set of metrics for assessing the degree of integration between production and quality controls. These were:

PPCQ (percentage of packages concluded with quality), which consists of the relation between the number of packages concluded with quality and the total number of packages concluded;

PPCR (percentage of packages really concluded), calculated by the ratio between the number of packages concluded with quality and the total number of planned packages. It represents a more accurate measure of PPC.

Later, Fireman et al. (2013) developed a basic model for performing these controls simultaneously in the short-term horizon of the LPS®. Furthermore, the same authors investigated the influence of this lack of integration in the occurrence of construction waste, such as rework, unfinished work and making-do. They also suggested that the generation of those types of waste are highly influenced by informal work (i.e. work that is not formally planned or controlled), which is a sign of the lack of effectiveness of planning and control systems.

Koskela (2004) defines making-do as a type of waste that occurs when a task is initiated before all items necessary for its completion are available. Informal work is usually represented by packages not included in the short-term plan that end up being done without any constraint analysis (Leão et al. 2014). Rework is a correction process for an item to enter in conformity with the original requirements or an unnecessary effort to redo processes or activities that were erroneously executed in the first time (Fireman et al. 2013). Viana et al. (2012) added that it is not clear in the literature whether rework is simply a consequence of quality deviation or if it is also a consequence of change orders or uncompleted tasks. Fireman et al. (2013) suggest that unfinished work is an incompletion that occurs when a work package (WP) is erroneously considered as concluded, postponing small finishing tasks and requiring the subsequent return of a crew to complete the work.

Marosszeky et al. (2002) criticize the fact that there often is a time delay between the completion of tasks and quality inspections. Thus, quality problems should be identified as close as possible to the time of the work being undertaken, since this would limit the generation of waste arising from the repetition of defective work. This should involve analysis, innovation, problem-solving and learning (Marosszeky et al. 2002).

Chen and Luo (2014) established three main difficulties for quality controls in construction: scattering of quality criteria in different norms and procedures, complexity derived from contracts and procedures, and controls focusing on final components rather than on the execution processes.

Considering these problems, several authors suggest that information technologies can considerably help the execution of control processes on-site as well as improve information flows related to control systems (Chen and Luo 2014; Chen and Kamara 2008; Irizarry and Gill 2009; Leão et al. 2014; Nourbakhsh et al. 2011).

REFINEMENT AND ADAPTATION OF THE CONTROL PROCESS MODEL TO THE COMMERCIAL SOFTWARE INTERFACE

Leão et al. (2014) proposed an integrated production control model, structured in three modules for monitoring task completion, quality conformance and making-do waste data collection, respectively. On a further development, Rocha (2015) devised a method for assessing the quality of work packages at different completion stages, instead of only based on the task after completion. Consequently, a division of quality criteria into two evaluation stages was proposed, i.e. starting conditions and work execution criteria. The former should be assessed before the beginning of each work package from the short-term plan, while the later, during task execution, until its conclusion.

Moreover, Rocha (2015) implemented the production control model by developing a mobile computing application, which was synchronized with a web cloud service. The same author also reported some technical difficulties in the development of the application regarding coding complexities, stability and robustness of the system, which are key issues for the maintenance of such a system. One alternative for that application is to implement the model in commercially available software tools (Chen and Kamara 2008). However, some adaptations are required, both in the software interface and in the proposed production control model. For instance, none of the existing software tools have mechanisms for monitoring making-do waste, or the incidence of informal work-packages in construction sites.

Based on the assessment of several tools available in the market, the chosen software applications were Autodesk's BIM 360 Field® (B3F) for on-site data collection and Navisworks Manage® for data analysis and processing inside BIM models. Particularly, B3F was chosen because it met the following requirements: (i) effective integration between production and quality control; (ii) flexible interface; (iii) works offline during data collection; (iv) allows taking photos and attaching documents during data collection, (v) allows data synchronization to a cloud service; (vi) exports data to a csv format, which enables the creation and management of databases; and (vii) allows the connection of the data collected to a BIM model. Other possible software alternatives were also analyzed. Nonetheless, some were not available for academic purposes (e.g. Amtech ArtrA, Bentley ConstructSim, Textura Latista, Aconex), while others did not allow an effective integration between production and quality control (e.g. Visilean, Dalux Field, BIM 360 Plan, BIManywhere).

RESEARCH METHOD

Design Science Research, also known as prescriptive research, was the methodological approach adopted in this study. It is a way of producing scientific knowledge that involves the development of an artifact to solve a real problem (March and Smith 1995; Vaishnavi and Kuechler 2013). This artefact must be assessed against criteria of value or utility (March and Smith 1995). In this research, the proposed artefact is the integrated production and quality control model, which was refined by adapting it to commercially available software.

The model was tested in two empirical studies, both of them carried out in residential building projects built by two different companies. Study 1 was a 19,700 m^2 low cost housing project being built in the South of Brazil, while Study 2 was a 32,100 m^2 higher middle class project being built in the Northeast of Brazil. The duration of those studies was 8 and 16 weeks, respectively. Both companies were chosen for the successful implementation of some Lean concepts and tools, such as the Last Planner System®, and *kanban* systems for delivering materials, and also for having a well established quality management system.

The main sources of evidence used in this investigation were: documents produced by the existing planning and control systems, participant observation during weekly planning meetings, direct observation of the construction sites (including quality problems, visual devices, etc.) and in-depth interviews performed with managerial staff.

All controls implemented by the research team were executed in parallel to the existing production controls. Due to constraints in terms of time and resources, production controls were limited to the short-term horizon of the LPS®. The checklists used for the quality inspections were established according to the quality procedures of each company. The categories for making-do waste, and informal work packages were obtained from previous works (Leão et al. 2014; Rocha 2015).The daily data collection routine was implemented in the B3F mobile app, while the information produced was visualized within Navisworks Manage®.

RESULTS

Although B3F has not been developed according to the requirements of LPS, it was flexible enough to fully incorporate the three main modules of the proposed integrated control process model, initially developed by Leão et al. (2014). Figure 9 presents the refined data collection model, including the adapted software nomenclature (i.e., see callouts in blue letters). This model allowed the systematic registration and collection of WPs planned in the short-term according to the LPS® as well as informal activities observed during the week. After registering data related to formal or informal WPs (i.e., name, type of work package, labor and location), their starting conditions, which correspond to quality controls, should be assessed. Then, the beginning of the activity is registered as well as any making-do waste associated to the WP under evaluation. Next, the general quality criteria related to the work under execution is checked. It is worth mentioning that these steps are carried out progressively during the week. The routine finishes at the end of the week with the assessment of the conclusion of each WP with quality. Moreover, feedback is sent to the weekly meeting in order to plan the activities for the following week (see Figure 9).

Regarding quantitative results, the Figure 10a summarizes the main categories of collected data and the average times for daily data collection in both empirical studies. Several analyses could be drawn from the data collected. Figure 10b shows the types of work packages observed in both studies and the relations among work packages, making-do waste and quality non-conformances. In this regard, the proportion of formal WPs were similar in both studies, i.e., 66% and 64% of the total packages, respectively. In addition, the distribution of the making-do waste according to the WP types was quite similar too, i.e., 57% and 53% of them were associated to the formal work packages, respectively.

However, there were significant differences in the degree of quality non-conformances in the two studies. They were linked to 58% and 68% of the formal WPs from the first and second study, respectively. The greater association to the formal WPs of the second study was induced by the large amount of informal activities without quality evaluation criteria, which indicated a necessity of improving the quality procedures of the company. Figure 11 shows the evolution of the PPC, PPIC, PPCQ and PPCR metrics over the weeks. The PPIC (i.e., Percentage of Packages Informally Concluded), was suggested in order to evaluate the effort spent by the work labor in order to conclude weekly informal activities. It consists of the relation between the number of informal packages concluded and the total number of informal packages controlled during the week.

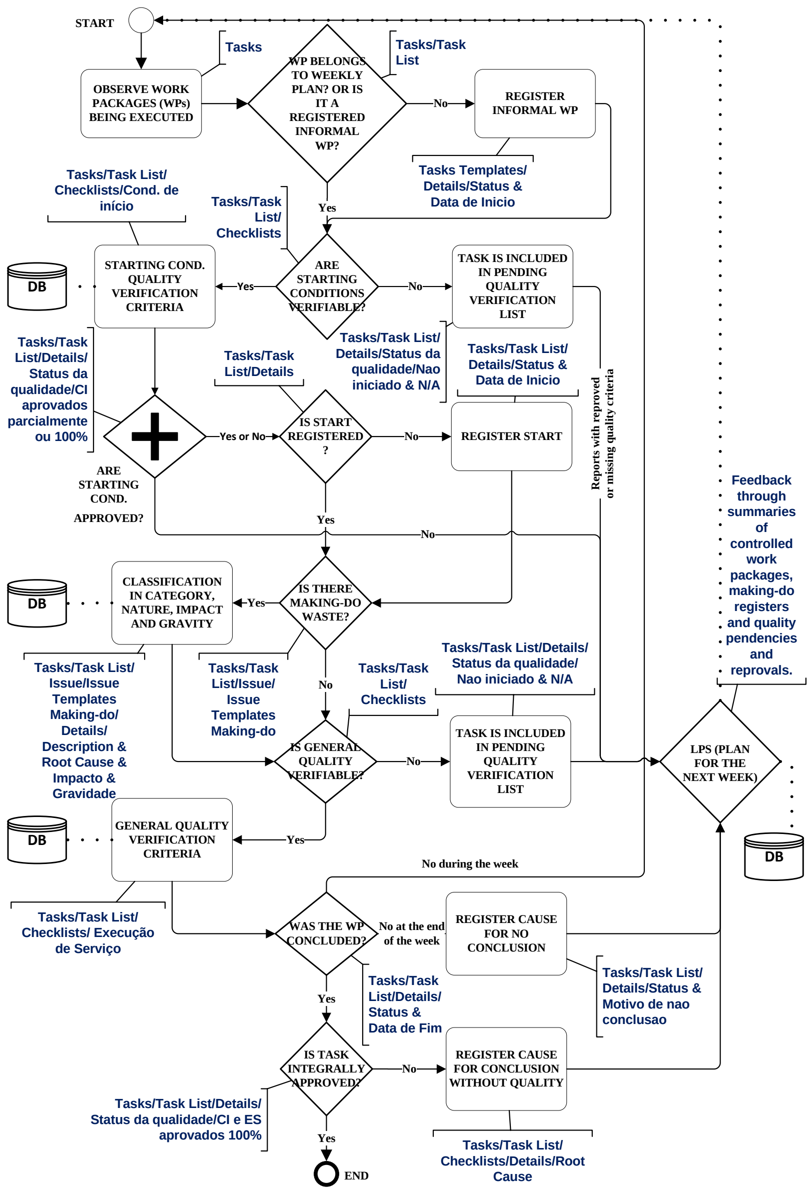

Figure 9: Integrated control model adapted to BIM 360 Field interface.

The average PPC, considering all weeks, were 33% and 64% for the first and second study, respectively. The extremely low PPC registered in the first study was mainly caused by inconsistencies in the planning and controlling activities. Meanwhile, the PPIC for the first and second study averaged 44% and 48%, respectively. This metric indicated a high effort carried out in order to conclude informal activities. These results were also a direct consequence of the failures in planning and controlling processes and had influenced the low conclusion rates obtained for the formal work packages, (see Figure 11).

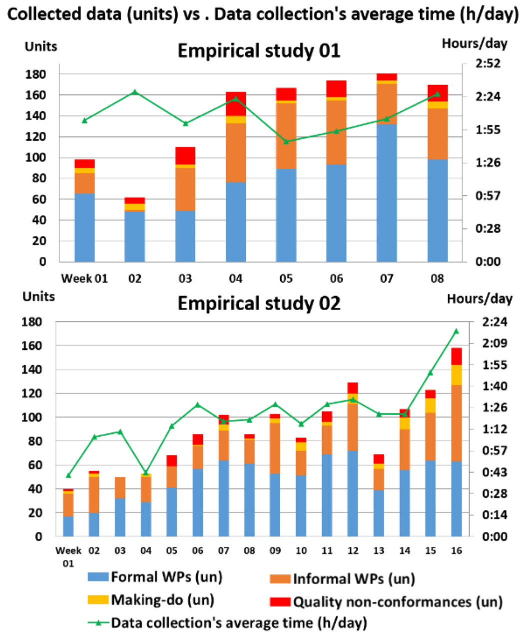

Figure 10a: Summary of data collected.

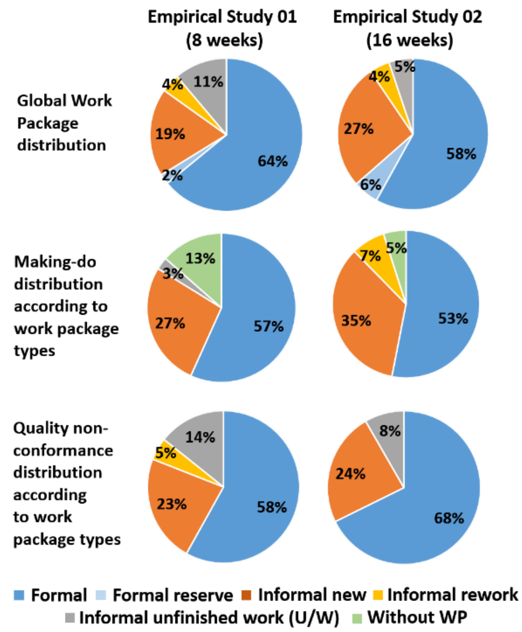

Figure 10b: Relations among work package types, making-do and quality non-conformances in both empirical studies.

It was also found that PPC and PPIC from both studies were in average 25% and 32% higher than the respective PPCR values. These results reflected that high percentages of the work packages were concluded but not integrally approved with quality. This gap was composed by cases of quality non-conformances and partially assessed quality. The former is related to situations where one or more quality criteria was not approved or was approved with restrictions, while the later regards to the lack of tools and resources that restrained the completion of each package's quality assessment. Moreover, the difference between PPCQ and PPCR, considering all types of WPs on both studies, averaged 19%. This metric indicated the influence that unfinished work had in the quality assessment process.

A connection between site control data and the product model was also made. Regarding the first empirical study, the B3F's mapping function was used in order to link the information collected on-site to a BIM model, which was then exported to Navisworks for visualization. However, due to some limitations in terms of the large amount of data to be transferred and a lack of information flow stability through the chosen software applications, a second method was tested for the next study. There, data from proactive controls was again collected on-site using B3F. Then, these data was exported and formatted in a database, to be finally linked through ODBC drivers to the BIM model in Navisworks, (see Figure 12). This final workflow proved to be less time consuming (i.e., an average of 8 hours/week against the 12 hours/week spent on the first study) and less error prone (i.e., crashes experienced during the mapping process of B3F and duplication errors due to different WPs associated simultaneously to the same BIM objects were avoided). Therefore, it opened the possibility to link several work packages to the same

BIM objects at the same time, which incremented the information visualization content inside the BIM object properties.

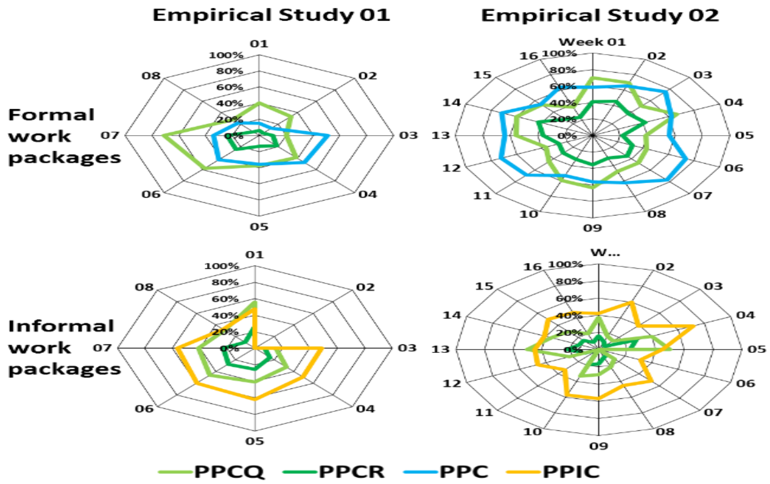

Figure 11: PPC, PPIC, PPCQ and PPCR metrics in empirical studies 1 and 2.

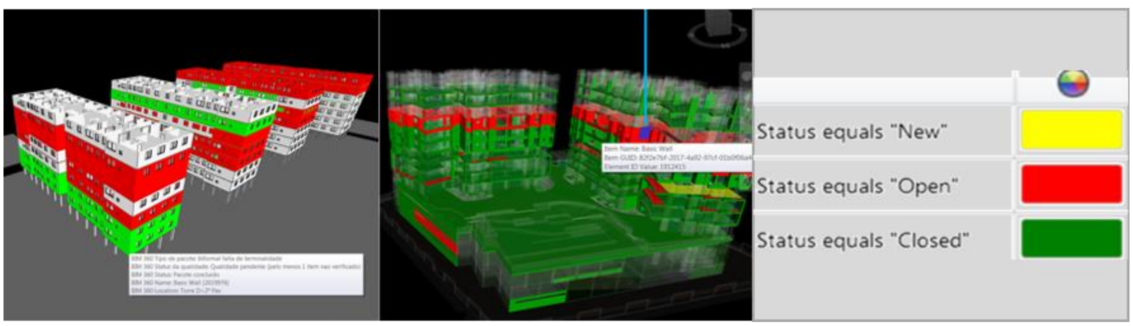

Figure 12: Production status visualization inside BIM models from both empirical studies.

It is worth mentioning that the average time spent on data collection for each study was 2:09 and 1:18 hours/day. This difference was attributed to the initial lack of familiarity with the data collection tool, the scattered distribution of the first site and the larger amounts of WPs in the first study due to its more advanced construction stage (i.e., an average of 141 against 89 data collection events per week). Even though, it is assumed that both times reflect the feasibility of utilizing this type of control method in construction sites (Figure 10a).

The lack of further involvement by the companies restrained the possibilities to implement the model in a more collaboratively manner, e.g., testing contractor’s production and quality self-assessment and reporting. In addition, inconsistencies during the execution of the planning and controlling activities, which affected the metrics previously presented, were observed in both companies. These were identified as deficiencies in the look-ahead constraint analyses, generating more informal activities, making-do and quality non-conformances. Moreover, the absence of a defined routine of activities during the week, induced both site supervisors to perform only occasional visual controls for the weekly planned activities. This led to difficulties in identifying work package statuses and to correctly plan the activities for the following weeks. Regarding the quality of work packages, the assessments on both companies were carried out separately from production controls and only to fulfil the system requirements, i.e., internal audits.

CONCLUSIONS

The adaptation of the integrated control model to the commercial software interface proved to be successful. Few customizations were needed in order to replicate the production, quality and making-do modules. Hence, this investigation highlighted that the commercial software architecture should be flexible enough in order to be adapted to innovative production control systems that attempt to implement some Lean concepts and tools.

Furthermore, ICT, particularly cloud computing and mobile technologies, allowed data collection and processing to become much less time consuming, making it possible to collect a larger amount of data that are concerned with non-value adding activities (e.g. making-do waste, quality non-conformances). These data was combined and processed in several instances to obtain metrics, graphs and perform various types of analyses. Other results related to making-do waste, quality non-conformances and informal activities were also obtained. However, due to the focus of this paper, they will be further analyzed in a following work.

Lastly, it was also possible to link site data to the BIM models of each project. Two different processes were tested, with different results regarding data flow stability and elapsing time for the BIM model enrichment. Future research should explore different methods for more efficient process and product models connection, i.e. algorithms for automating these links.

REFERENCES

Akinci, B., Boukamp, F., Gordon, C., Huber, D., Lyons, C., and Park, K. (2006). “A formalism for utilization of sensor systems and integrated project models for active construction quality control.” *Automation in Construction*, 15(2), 124–138.

Arentsen, A. L., Tiemersma, J., and Kals, J. (1996). “The integration of quality control and shop floor control.” *International Journal of Computer Integrated Manufacturing*, 9(2), 113–130.

Ballard, G. (2000). “The Last Planner System of Production Control.” Faculty of Engineering, University of Birmingham, Birmingham, Thesis (Ph.D) - School of Civil Engineering.

van der Bij, H., and Ekert, J. H. W. Van. (1999). “Interaction between production control and quality control.” *International Journal of Operations & Production Management*, 19(7), 674–690.

Chen, L., and Luo, H. (2014). “A BIM-based construction quality management model and its applications.” *Automation in Construction*, Elsevier B.V., 46, 64–73.

Chen, Y., and Kamara, J. M. (2008). “Using mobile computing for construction site information management.” *Engineering, Construction and Architectural Management*, 15(1), 7–20.

Fireman, M. C. T., Formoso, C. T., and Isatto, E. L. (2013). "Integrating production and quality control: monitoring making-do and informal work packages." *21th Annual Conference of the International Group for Lean Construction*, (March 2016), 515–525.

Irizarry, J., and Gill, T. (2009). "Mobile Applications for Information Access on Construction Jobsites." *Computing in Civil Engineering*, 176–185.

Koskela, L. (1992). "Application of the new philosophy to construction." Center for Integrated Facility Engineering, Salford, CIFE Technical Report, n. 72.

Koskela, L. (2004). "Making-do - The Eighth Category of Waste." *Proceedings of the 12th Annual Conference of the International Group for Lean Construction*.

Leão, C. F., Formoso, C. T., and Isatto, E. L. (2014). "Integrating Production and Quality Control with the Support of Information Technology." *22h Annual Conference of the International Group for Lean Construction*, 847–858.

March, S. T., and Smith, G. F. (1995). "Design and natural science research on information technology." *Decision Support Systems*, 15(4), 251–266.

Marosszeky, M., Thomas, R., Karim, K., Davis, S., and McGeorge, D. (2002). "Quality management tools for lean production-moving from enforcement to empowerment." *International Group of Lean Construction*, 1–13.

Nourbakhsh, M., Mohamad Zin, R., Irizarry, J., Zolfagharian, S., and Gheisari, M. (2011). "Mobile Application Information Requirement in Construction Industry." *Construction Challenges in the New Decade*, Kuala Lumpur, Malaysia, 843–852.

Rocha, G. S. (2015). "Proposta de Refinamento de Modelo de Controle Integrado da Produção e Qualidade com o uso de Dispositivos Móveis." M.Sc. Dissertation, Federal University of Rio Grande do Sul, Porto Alegre (in Portuguese).

Sukster, R. (2005). "A integração entre o sistema de gestão da qualidade e o planejamento e controle da produção em empresas construtoras." M.Sc. Dissertation, Federal University of Rio Grande do Sul, Porto Alegre (in Portuguese).

Vaishnavi, V., and Kuechler, B. (2013). "Design Science Research in Information Systems Overview of Design Science Research." <http://desrist.org/desrist/content/design-science-research-in-information-systems.pdf> (Aug. 17, 2015).

Viana, D. D., Formoso, C. T., and Kalsaas, B. T. (2012). "Waste in Construction: a Systematic Literature Review on Empirical Studies." *20th Annual Conference of the International Group for Lean Construction*, 10.