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The influence of changes in construction productivity: a state of the art review

La influencia de los cambios en la productividad de la construcción: una revisión del estado del arte

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Abstract

Multiple studies have found that productivity in Chilean construction has been stagnated during recent decades; thus, creating the need to understand better what factors have led to these results in the construction sector. In the international literature, studies have found that changes are the leading cause of productivity losses in construction projects; however, limited studies have been done in Chile in this regard. This context is understood as an opportunity to learn from the existing literature about the impact of changes in construction productivity, more importantly, such learning can contribute to the discussion of productivity improvement in the Chilean construction sector. This study recommends that more studies are necessary to be done in Chile regarding the impact of changes in construction projects. Namely, future studies should be based on an extensive database of projects so that generalization can be drawn for the construction industry. Additionally, the data collection process of changes in construction should be improved, paying specific attention to the size of changes, the timing of changes, and the scale of assessment—namely activity, project, and industry levels. Ultimately, this study aims to contribute to the discussion about productivity improvement in Chilean construction as this remains one of the main challenges in the industry.

Keywords: Change orders; construction projects; Chilean construction

Resumen

Múltiples estudios han encontrado que la productividad en la construcción chilena se ha estancado durante las últimas décadas; creando así la necesidad de comprender mejor qué factores han llevado a estos resultados en el sector de la construcción. En la literatura internacional, los estudios han encontrado que los cambios son la principal causa de pérdidas de productividad en los proyectos de construcción; sin embargo, se han realizado estudios limitados en Chile al respecto. Este contexto se entiende como una oportunidad para aprender de la literatura existente sobre el impacto de los cambios en la productividad de la construcción, lo que es más importante, dicho aprendizaje puede contribuir a la discusión de la mejora de la productividad en el sector de la construcción chileno. Este estudio recomienda que se necesiten más estudios en Chile sobre el impacto de los cambios en los proyectos de construcción. Es decir, los estudios futuros deben basarse en una amplia base de datos de proyectos para que se puedan generalizar para la industria de la construcción. Además, el proceso de recopilación de datos de cambios en la construcción debe mejorarse, prestando especial atención al tamaño de los cambios, el momento de los cambios y la escala de evaluación, es decir, niveles de actividad, proyecto e industria. En definitiva, este estudio tiene como objetivo contribuir a la discusión sobre la mejora de la productividad en la construcción chilena, ya que este sigue siendo uno de los principales desafíos de la industria.

Palabras clave: Órdenes de cambio; proyectos de construcción; construcción chilena

1. Introduction

During the designing and planning stage of a construction project, design professionals make different estimations and assumptions about how the project will be constructed, such as what construction methods and materials, or the estimations of the budget and schedule of the project. However, a variety of factors can modify estimations and assumptions made, such as unexpected weather conditions, differing site conditions, and errors and omissions on the design documents (Oglesby et al., 1989). Therefore, when the construction stage begins, many of the assumed conditions are different; thus, creating the necessity of changes. A change is understood as any deletion, addition, or revision to project goals and scope (Ibbs et al., 2001). In fact, in the construction industry, changes are recognized as fairly common or even inevitable (Ibbs, 2005); (Shipton et al., 2014). Likely due to the regularity in which construction projects face changes is that the impact of changes and how to manage them has been extensively documented in the literature (Du et al., 2015); (Ibbs et al., 2001); (Ibbs, 2005); (Ibbs, 2012); (Lee et al., 2004); (Leonard, 1988); (Thomas and Napolitan, 1995).

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Multiple studies have identified changes in construction projects as the leading cause of negative effects on projects, such as time delays and cost overruns (Choi et al., 2015); (Marzouk and El-Rasas, 2014); (Sweis et al., 2008), loss of productivity (Ibbs, 2012); (Leonard, 1988); (Moselhi et al., 2005), and claims and disputes (Alnuaimi et al., 2010); (Chen and Hsu, 2007); (Duah and Syal, 2017). As such, it becomes relevant for the industry and practitioners to understand better how to manage change during construction projects to minimize its negative impacts on construction projects (Du et al., 2015). As multiple studies have emphasized that the productivity in the construction sector is a fundamental driver for the economic growth of the sector (Abdel-Wahab and Vogl, 2011); (De Solminihac and Daga, 2017); (Sveikauskas et al., 2016), a better understanding of the factors impacting construction productivity can be beneficial to the construction researchers and industrial practitioners from different perspectives, namely industry, project, and activity levels (Yi and Chan, 2013). As such, this study is focused on the impact of changes in construction productivity, acknowledging changes in construction as one of the main factors impacting construction productivity.

The rest of this study is organized as follows: the study discusses the existing international literature regarding the impact of changes in construction productivity, it is followed by the discussion of novel approaches implemented to study changes management in construction. Then, it discusses the existing literature specific to the Chilean construction. Finally, a discussion regarding how the Chilean sector can learn from the international experience to face existing challenges and move forward, as recent studies have reported that the construction productivity growth in the Chilean sector has been stagnated during the last decades. This study aims to contribute to the conversation between our academic and professional construction community regarding challenges and future research ideas to improve productivity in the Chilean construction industry.

2. Background research

Multiple articles have been written on the subject of changes in construction projects over the years (Ibbs, 2005); (Ibb, 2012); (Khalafallah and Shalaby, 2019); (Leonard, 1988); (Thomas and Napolitan, 1995), as such, covering different aspects such as causes, qualitative impacts, change management process, and cumulative effects. The following literature review describes and analyzes the contribution of the most relevant studies following a chronological order.

Charles Leonard's thesis is one of the earliest and most widely known research work on the subject of the quantitative impact of change. (Leonard, 1988) examined 90 cases drawn from 57 projects and organized them into civil/architectural and electrical/mechanical work. (Leonard, 1988) also organized the projects into those that reported change orders only, change orders with one major cause of delay, and change orders with two or more causes of delay. Leonard reported that the major causes of change orders were design errors and omission, design changes, and unforeseen conditions. Statistical models were implemented that developed statistical correlations between change orders only, changes with one major cause of delay, and changes with two or more causes of delay, and productivity. Leonard's study found that large amounts of change create larger amounts of productivity loss, and change orders can cause productivity loss on both the change work and the base contract work. Nonetheless, despite the foundational nature of Leonard's work, it has been subject to criticisms (McEniry and Ibbs, 2007). One criticism is that the study considered projects that had reached the dispute stage and as such, results were not representative of the general population of projects.

(Thomas and Napolitan, 1995) analyzed the effect of changes and change orders on labor productivity efficiency. Data used were daily productivity of electrical and piping crafts from three industrial projects constructed between 1989 and 1992, completing 522 workdays of data. The authors performed a statistical analysis including analysis of variance and multiple regressions to analyze the quantitative effect of changes on labor efficiency and the influence of individual factors such as the performance ratios of changes, rework, disruptions and weather. Finding that changes are highly correlated to the performance ratio, rework, and disruptions. Interestingly, the influence of disruptions suggested that the principal factor affecting labor efficiency is the timing of the change. Finally, the author stated that, on average, there is a 30% loss of efficiency when changes are performed, and lower performance is strongly related to the presence of change work, disruption, and rework. The most relevant types of disruptions found were the lack of materials and information and having to perform the work out-of-sequence.

(Ibbs, 1997) studied the nature and impacts of projects change during the detailed design stage and construction of 104 different projects, focusing on the size of the change and its impact on the project. The author developed a regression analysis between design phase productivity versus design phase changes, and construction phase productivity versus construction phase change, and found that in each case, productivity declines noticeably as more changes are incurred. Hanna and colleagues studied the impact of change orders on labor efficiency for electrical and mechanical construction (Hanna et al., 1999a); (Hanna et al., 1999b); and (Hanna, 2001); (Hanna



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and Iskandar, 2017). The author performed a regression analysis for mechanical and electrical projects; in both cases, the models were validated with data from new projects. For the mechanical projects, the author found that there was a substantial difference in labor efficiency between impacted and non-impacted projects.

Additionally, the later a change order occurs during the project, the more impact it will have on labor efficiency (Hanna et al., 1999a). When it comes to the electrical projects, the author found that there is a direct relationship between change orders and schedule compression stacking of trades, and the sequencing of work (Hanna et al., 1999b). Interestingly, a key finding was that larger projects have a higher capacity for absorbing a loss of efficiency caused by changed work. Therefore, the loss of the labor efficiency for a project decreases as the size of the project increases—the size of a project was expressed in terms of work hours.

(Hanna and Gunduz, 2004) studied the impact of change orders on small, labor-intensive projects, developing a linear regression model for determining and quantifying the effect of change orders on labor efficiency. Hanna and Gunduz focused on small projects hypothesizing that small projects are typically shorter in duration, making it more difficult to handle the changed work without affecting productivity. Additionally, arguing that on small projects is more challenging to reassign large groups of workers to different locations when changes are made. The developed model included five variables: percent of changes that were design changes or errors, percentage of changes initiated by the owner, ratio of the actual and estimated peak of labor, ratio of the actual and estimated duration of the project, time spent by the project manager on the project. Hanna and Gunduz validated the model with data from a new project, and the model estimated the productivity loss with 91.5% of accuracy.

(Ibbs, 2005) assessed the impact of change timing in 162 disputed and undisputed projects using linear regressions between construction productivity and timing of the change. Ibbs defined early changes (25% of projects where changes were recognized fastest), normal changes (middle 50%), and late changes (25% of projects where changes were recognized slowest). The author found that late changes are more detrimental to the productivity of the projects than early or normal changes. Therefore, the implications of the finding are clear: under all other conditions being equal, early changes should be encouraged, and late changes discouraged (Ibbs, 2005). The problem of change orders gets even worse if changes have a cumulative impact. The cumulative impact may result from changes that delay the schedule or disrupt the work and are very likely to damage productivity. Disruptions may occur during any stage of the project, but ripple through the project to damage the productivity of a later stage. In this context, to further clarify the impact of changes, (Ibbs, 2012) addressed the quantitative aspects of changes defined as frequency, severity, and impacts on labor productivity. Data from two independent studies that contained 226 projects were analyzed to quantify the impact of change on project cost, schedule, and productivity. The author found that 59% of all projects had 10% or less changes, which was suggested by (Leonard, 1988) as a limit value to consider that a cumulative impact condition may exist.

In summary, the international literature provides a clear idea that although changes are sometimes necessary for construction projects (e.g., unforeseen conditions, and flexibility of design), changes invariably affect construction projects, and changes should, therefore, be authorized cautiously and conservatively paying special attention to the size and timing of the changes compared to the scope of the construction project.

3. Novel research approaches

A large portion of the literature about the influence of changes in construction productivity is based on elemental statistical analyses (e.g., linear regressions). More recently, however, new and more sophisticated approaches have been used based on the premise that is not enough to only recognize and quantify the influence that changes have on productivity but also is needed a thorough understanding of the root causes and dynamic relationships between construction changes and productivity e.g., (Du et al., 2015); (Hanna and Iskander, 2017). As such, novel approaches are not only focused on quantifying the impacts of changes, but also on a more comprehensive understanding of the different causes of changes as well as how these causes may be interrelated (Khanzadi et al., 2018).

For example, (Du et al., 2015) proposed an object-oriented Discrete Event Simulation model to investigate the management process of change orders. A factor that contributes to the inefficiency of change order management is the suboptimal allocation of resources and unnecessary procedures related to a defectively organized management process. The complex approval process and congestion effects increment the response time of many change orders, leading to increased construction time and cost. Thus, optimizing the management process of change orders may help to reduce the cost and time of processing change orders. The proposed model was tested using 130 change orders of 19 construction projects. The study concluded that the Discrete Event Simulation approach could be applied to analyze change orders management, and three potential improvements to the change orders management process



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were identified: optimizing the number of items on each change order, accelerating activities, and re-engineering process (Du et al., 2015).

Similarly, (Khanzadi et al., 2018) implemented a fuzzy cognitive map (FCM) approach, which has the capabilities to study the causes of changes in construction projects taking into account how different causes may interact in the causation of changes to construction projects. The authors implemented the model in a real project, finding that the proposed method facilitated the management of changes orders as root causes of changes could be prioritized by the project manager in charge of the construction project. More importantly, identifying the root causes of changes is a first step toward mitigating the changes, which can decrease changes and its negative disruptions on construction projects.

Another example is the work of (Hanna and Iskander, 2017), who developed a study implementing a regression model to predict the cumulative impact of changes in electrical and mechanical construction projects. The approach supplements the traditional regression analysis followed by previous studies, implementing multiple variable selection criteria, statistical check for multicollinearity, and also considers the existence of outlying of influential data points. (Hanna and Iskander, 2017) found that, in general, the best desirable approach is that owners and contractors track the potential cumulative effect of changes throughout the execution of the project to agree upon the amounts of productivity loss. However, this would require exceptional circumstances in construction, such as collaboration, mutual trust, and efficient and transparent communication. If the negotiation between owner and contractors fails, the developed model could be used as an alternative to quantify the incurred productivity loss.

In summary, recent studies claim that existing methods used to understand the impact of changes in construction productivity have been adequate to quantify the impact of changes in productivity; however, past methods are inadequate in providing a more comprehensive understanding of the root causes of changes and how these disrupt the productivity in construction projects.

4. The study of productivity in the Chilean construction

There are multiple studies about construction productivity in the Chilean context e.g., (Arriagada and Alarcon, 2014); (Idrovo-Aguirre and Serey, 2018); (Martínez and Alarcon, 1988); (Serpell, 1986). In the '80s, the first studies already emphasized the low productivity in the Chilean construction sector, and that productivity improvement programs were necessary (Serpell, 1986); (Martínez and Alarcon, 1988). Further, (Martínez et al., 1990) provided practical recommendations based on their experience as consultants to construction companies, emphasizing factors, such as the motivation of the workers, better crew planning, and the need for more accurate and detailed planning of the activities. More recently, (Araya et al., 2016) demonstrated that using a zero-waste management approach can also be beneficial in terms of productivity improvements in construction. Important to notice, however, these studies were focused on improvements at either the activity or project level.

When it comes to the study of the influence of changes on construction productivity, limited studies have been done in Chilean construction projects in this regard (Arriagada and Alarcon, 2014); (Acevedo, 2015). Only recently, (Arriagada and Alarcon, 2014) assessed the impact of work schedule changes on productivity in a mining construction in the north of Chile, implementing computer simulations. Similarly, (Acevedo, 2015) compared different methods available in the literature to assess productivity losses due to changes during the construction of a mall. (Acevedo., 2015) concluded that the most convenient approach to effectively control productivity in construction is to keep updated records during the construction of the project; however, the authors also mention that this is not a frequent practice in the Chilean construction industry. A significant limitation of these two studies, nonetheless, is that the analysis of each study is based on only one construction project, which represents a limitation to transfer their findings to other projects and the construction industry.

5. Discussion

As reported by multiple Chilean institutions, the growth of construction productivity has been lower compared with the national economy; what is more, the construction productivity has been stagnated during the last two decades (CORFO, 2019); (De Solminihac and Dagá, 2017); (De Solminihac and Dagá, 2018). Notably, this challenge is not exclusive from the Chilean construction industry, and similar results have been reported in the United States, Europe, and Asia (Abdel-Wahab and Vogl, 2011); (Rojas and Aramvareekul, 2003); (Sveikauskas et al., 2016). As discussed in the literature review section, changes in construction projects represent a leading cause of productivity losses in construction projects. Furthermore, the regularity in which projects are subject to changes—often recognized as inevitable—reinforces the importance of understanding better the role of changes in improving the productivity of the Chilean construction industry. The first aspect that is highlighted when comparing the international and the



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Chilean literature is the limited number of studies existing in the Chilean literature (Arriagada and Alarcon, 2014); (Acevedo, 2015). Moreover, as these studies used only one project as a sample size, the transferability of their results to the construction industry is limited. As such, researchers and practitioners from the construction sectors should be encouraged to work together and develop more studies looking for the impact of changes in the construction projects not only at the project level but also looking to expand the sample size involved in the studies as well as looking at different scales of analysis—e.g., at the activity and industry level. Additionally, research efforts should be made to identify mechanisms in which integrated efforts of all stakeholders from the industry, firm, and project team levels can be attained, as suggested by (Yi and Chan, 2013). By doing so, it would be possible to draw generalizations of the findings that may apply to the Chilean context.

A second aspect highlighted by the comparison undertaken in this study between the Chilean and the international literature is that researchers and practitioners of the Chilean construction sector must be able to collect better information to have a more comprehensive understanding of the impact of changes in construction productivity, as discussed by (Acevedo, 2015). In this regard, the international literature emphasized the importance of having a good understanding of the size and the timing of the changes in construction projects, and as such, record-keeping these attributes of changes during construction projects will be fundamental. Furthermore, the collection of better information about changes in construction projects will facilitate the implementation of novel techniques that can assess more comprehensive attributes of changes, such as root causes. Interestingly, the necessity to collect better information in projects can be matched with existing initiatives from the construction sector. For instance, the initiative from the Chilean chamber of construction (CChC) and the Chilean Ministry of economy of implementing BIM technologies in all public infrastructure projects executed by 2020 (CChC, 2017a); (CChC, 2017b).

6. Conclusions

This study explores the gaps between international literature and the studies done in the Chilean construction context regarding the influence of changes in the productivity of construction projects. This study found that the Chilean literature falls well behind compared with the international literature; however, this is also understood as an opportunity for the Chilean construction community to learn from the international experience. As such, based on the main lessons learned from the international experience, recommendations are made to encourage the discussion that our construction community may need while facing the existing challenges of improving the productivity of our construction projects in Chile.

The main findings of this study are first that future studies in Chile should be based on larger sample sizes (i.e., number of projects from where data was collected), as such, results and trends can be generalized to the industry level. Second, better information must be collected when it comes to the quantification of changes in construction projects; namely, the literature emphasized the relevance of the size and timing of changes in construction projects. Third, the impact of changes in construction productivity should be assessed using different levels, namely, at the activity, project, and industry level. Moreover, mechanisms to encourage the interaction and collaboration between all the project stakeholders involved in these three levels should be pursued (e.g., owner, designers, contractors, subcontractors), as the challenge of managing changes in construction projects is unlikely to be solved by any of the stakeholders alone.

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