# UNDERSTANDING INTERACTIONS BETWEEN DESIGN TEAM MEMBERS OF CONSTRUCTION PROJECTS USING SOCIAL NETWORK ANALYSIS

Rodrigo F. Herrera, Ph.D (c)[1]; Claudio Mourgues. Ph.D.[2]; Luis F. Alarcón, Ph.D., M. ASCE[3]; and Eugenio Pellicer, Ph.D., M. ASCE[4]

## Abstract

Social Network Analysis (SNA) has not been used to study design project teams in which the full interactions have become more complex (formal and informal) because the team members are from different companies and there is no collocation. This work proposes a method to understand the interactions in the design teams of construction projects using SNA metrics and the sociograms generated within temporary organizations. This study includes three stages: (1) a literature review of the dimensions of interactions within work teams and the application of SNA to the architecture, engineering and construction (AEC) industry; (2) a proposal of an interaction network method for construction project design teams; and (3) an analysis of a pilot project. Interaction networks were defined in two categories: general interactions and commitment management. For each network, metric indicators were defined for the analysis. The pilot project showed high levels of consistency among team responses. The proposed method allows an analysis of the entire work team and of each individual team member. The

[1] Instructor, School of Civil Engineering, Pontificia Universidad Católica de Valparaíso, Avenida Brasil 2147, Valparaíso, Chile and PhD (c) Pontificia Universidad Católica de Chile, Santiago, Chile and Universitat Politècnica de València, Valencia, Spain, e-mail: rodrigo.herrera@pucv.cl
[2] Associate Professor, Dept. of Construction Engineering and Management, Pontificia Universidad Católica de Chile, Vicuña Mackenna 4860, Santiago, Chile, e-mail: cmourgue@ing.puc.cl
[3] Professor, Dept. of Construction Engineering and Management, Pontificia Universidad Católica de Chile, Vicuña Mackenna 4860, Santiago, Chile, e-mail: lalarcon@ing.puc.cl
[4] Professor, School of Civil Engineering, Universitat Politècnica de València, Camino de Vera s/n, 46022 Valencia, Spain, e-mail: pellicer@upv.es

method also makes it possible to analyze the work team from a global perspective by carrying out a joint analysis of two or more networks.

***Keywords***: *interaction, interaction metrics, sociograms, information flow, design teams, social networks*

## INTRODUCTION

The architecture, engineering and construction industry (AEC) is fragmented into several specialties that correspond to the different phases of a project (Dainty et al. 2001; Love et al. 2002). A high degree of fragmentation requires better interaction between the specialties (Ng and Tang 2010). The interaction of a work team is generated through communication, coordination and collaboration among the participants (Schöttle et al. 2014). This interaction can be represented as the information flow between the right people at the right time (Dave et al. 2014; Al Hattab and Hamzeh 2015).

Poor interactions in work teams can lead to poor performance, both in the implementation of each phase (design, construction, maintenance, operation and deconstruction) and globally in the life cycle of the project (Baiden et al. 2006). This phenomenon is particularly important at the design phase because decisions made at this phase can significantly affect the following phases, and the cost of making changes at this phase are insignificant compared with the cost of implementing changes in future phases (American Institute of Architects California Council 2007).

The client usually chooses a project coordinator or design manager at the design phase of a construction project to lead this phase and manage the interaction between all the specialists, such as architects, structural, electrical and sanitary specialists, and others

(Knotten et al. 2017; Oluwatayo and Amole 2013). Because the AEC industry is fragmented, the level of subcontracting of the specialties has been increasing in recent years (Oviedo-Haito et al. 2014).

More fragmentation requires more interaction, which must be approached by considering the social and technological factors. These factors together allow the information flows to be suitable for the desired interaction. A project team with greater interaction may generate an increase in trust and learning in work teams, achieving high levels of commitment and understanding between the participants (Phelps 2012). Flores et al. (2014) claim that by improving the interaction of information flows between people, improved project performance can be achieved. An interaction in a work team can be represented as a network of commitments among its members, who establish reliable commitments among themselves, to achieve the objectives of the project (Viana et al. 2011).

Evaluation of the interactions between members of a work team is challenging. One approach to this issue is to measure teamwork with instruments; Valentine et al. (2015) present a literature review from 2012 in which 39 instruments are identified for measuring teamwork with surveys. Most of these instruments include dimensions such as communication, coordination and respect. Although the study by Valentine et al. (2015) includes a large number of instruments that evaluate teamwork, these instruments carry out a general evaluation of an organization and thus do not allow the identification of the frequency and dimension of interaction that is generated between the people within the organization who participated in the surveys. In addition, many of the instruments that measure teamwork evaluate it from either an individual or a global perspective, but not both (Paris et al. 2000).

A tool for assessing interaction from an individual and a global perspective simultaneously is Social Network Analysis (SNA), which has been used to evaluate the information flow in AEC industry organizations (Alarcón et al. 2013). SNA uses graph theory to explain the relationships that exist among a group of people based on mathematical metrics, such as the density, length and diameter of the network and other metrics (Marin and Wellman 2011).

There are studies evaluating the social networks in the AEC at an organizational or company level (Castillo et al. 2018a; Segarra et al. 2017) or at the level of a construction project (Castillo et al., 2018b) in which all the participants are from the same workplace. These studies use standard social network metrics for all the dimensions of interactions without providing a specific interpretation for each network. In addition, such metrics are applicable to large organizations, and they are difficult to interpret in small work teams, such as temporary organizations created during the design phases of construction projects. A large organization is defined as one that exceeds the limits of medium-sized companies (250 people) and small companies (49 people) (European Commission 2003); however, it is difficult to clearly define the size of a network to characterize it. Richards and Macindoe (2010) propose that a small network is one with fewer than 100 members, while a large network has more than 1000 nodes. Therefore, design project teams are small social networks because the number of members is fewer than 50 people. According to a previous report (Segarra et al. 2017), when a network is small, there is a greater possibility of sharing important information because the network facilitates interaction among its members.

Previous studies on social networks in the construction industry provide valuable information mostly about large organizations (e.g., Flores et al. 2014) in construction companies of more than 100 employees. However, there are fewer studies analyzing small groups (fewer than 50 people); there are only preliminary studies of architecture (Segarra et al. 2017) and construction teams (Priven and Sacks 2013). In addition, these studies do not include an evaluation of the interaction from the perspective of the commitment network among the members of a team. SNA has been carried out in design teams with participants from different companies using information obtained from BIM log files that are registered in collaborative design software (Zhang and Ashuri 2018); however, this methodology can only be used in BIM design environments, and certain informal communicative actions typical of the design process are lost, such as telephone calls and face-to-face conversations.

SNA has not been used to study design project teams in which the full interactions have become more complex (formal and informal) because the team members are from different companies and noncollocation obstructs the information flow. Design teams play a very important role because they create design concepts. During the design process, the teams adjust the client's requirements to the project before the planning phase (Oluwatayo and Amole 2013). To perform this task, the design offices form multidisciplinary working groups within their own or with other organizations, and these groups are divided into task teams (Sonnenwald 1996). This project approach has evolved from a tool-oriented understanding of projects, in which it is compared with a production function that transforms inputs into outputs through mathematical formulation and planning (Turner and Müller 2003), to a consideration of the project as a temporary organization (Sydow and Braun 2018). In contrast to the social networks of construction companies, the social networks in design offices are generally small and have greater change dynamics due to the short duration of their production processes (Pryke 2012).

Considering this knowledge gap, this study proposes a method to understand different dimensions of the interactions in construction project design teams through the analysis of social network metrics and sociograms generated within these types of temporary organizations, in which the members of the design teams are from different companies.

## RESEARCH METHODOLOGY

To achieve the objective of this work, the research was divided into three stages: (1) a literature review of the dimensions of interactions evaluated in the AEC industry and different experiences of SNA implementation, (2) a proposal for an interaction network method (measurement and analysis) for construction project design teams, and (3) an evaluation and analysis of a pilot project to exemplify the use of the tool. These stages are displayed in Fig. 1.

In the first stage, a literature review of specialized journals in engineering and construction project management and of the proceedings of major conferences held between 2008 and 2019 was carried out. The search was carried out in the following online libraries: Engineering Village, Web of Science and Scopus. The topics sought were interaction, teamwork, team effectiveness, SNA, team integration and team collaboration; all the papers selected were from the AEC industry. This first review aimed to identify the dimensions of teamwork, which can be defined as an interaction between two or more people in a design team. The literature review identified a perspective of the interaction of work teams associated with the commitment network generated among them. Therefore, a list of dimensions of interaction was compiled and grouped into two categories: traditional interaction and commitment management. In addition, a review of the literature associated with the use of SNA in the AEC industry was conducted. Some metrics and characteristics of this type of analysis were presented, exemplifying different case studies reported in the literature. Finally, the gap between the dimensions of the interactions associated with an effective team and the use of SNA in the AEC industry was identified.

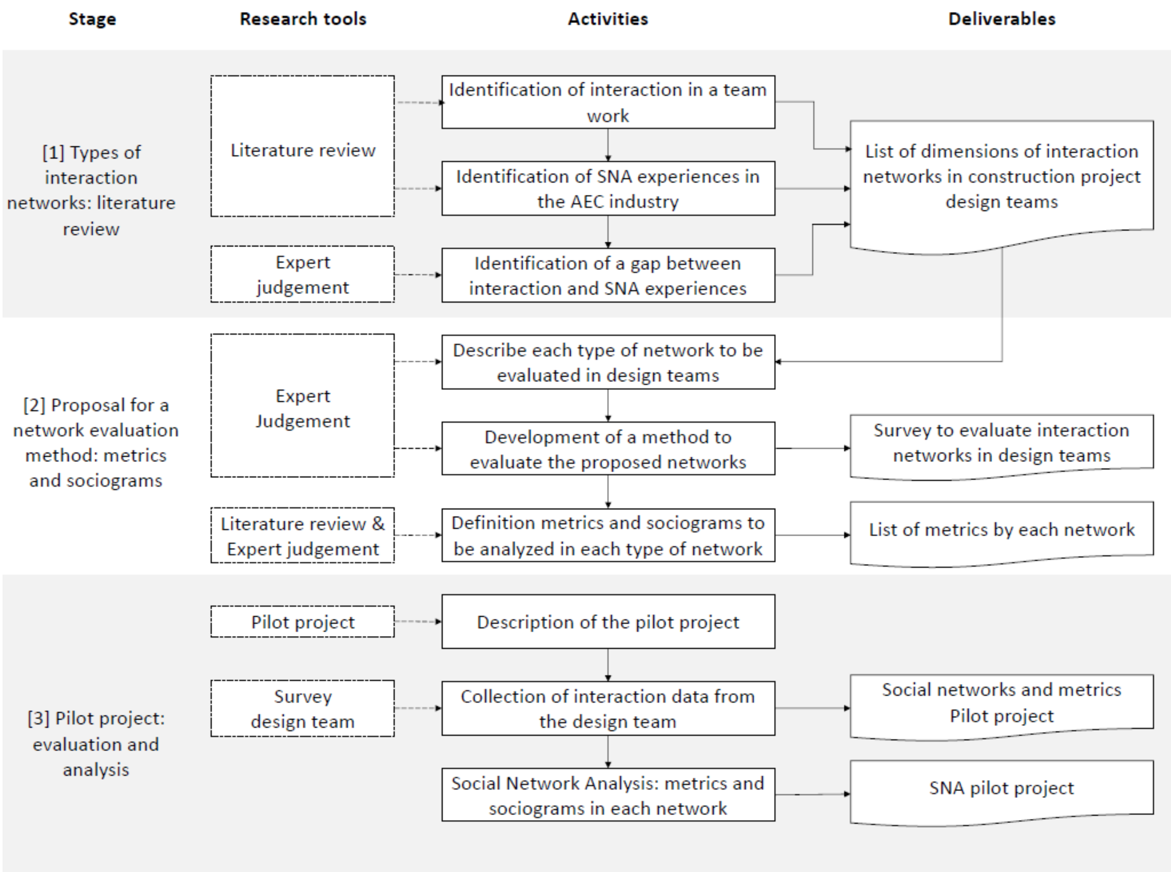


**Fig. 1.** Research methodology stages

In the second stage, the authors proposed a method to assess the interaction in a design team of a construction project, using the design team as the unit of analysis. The list of interaction dimensions for this type of project was the input to develop this stage, and the team developed the interaction network method for the design teams of construction projects in four multidisciplinary work sessions that included engineers, architects, builders, consultants and linguists. In the first session, the team described each dimension of interaction that would be evaluated in this type of project and the type of link framed in the SNA. In the second and third sessions, the team created the data collection survey and identified the objective of the instrument, potential survey participants and distribution method. In the fourth session, based on a review of the literature and its experience, the team defined the metrics and sociograms that should be analyzed in each of the networks, as well as the validation criteria. The final deliverable of this stage was the network evaluation method in construction project design teams, which included a description of the interaction dimensions, definitions of each interaction link type, the survey participants, the collection method and the questions for the data collection, data validation, and definitions of the metrics and sociograms to be analyzed for each interaction dimension.

In the third stage, the proposed SNA method was applied to a pilot project with the objective of exemplifying the use of this method in terms of implementation and analysis. The pilot project was a design team for a residential building project in the city of Santiago, Chile. First, the main characteristics of the pilot project were described, e.g., project type, location, members of the design team and some specific characteristics. Then, the researchers collected interaction data from the design team through an online survey server (the survey created in phase 2 was used). The input data were validated according to the criteria proposed in the coherence analysis. Next, the metrics of each dimension of interaction were calculated, and the sociograms were graphed. Finally, the authors interpreted these metrics and graphs according to the literature review.

# LITERATURE REVIEW OF INTERACTION NETWORKS

This section is divided into three parts: the first part explains the different dimensions of interaction that are generated in a work team; the second part describes some experiences of using SNA in the AEC industry and identifies which dimensions of interaction were evaluated and which metrics were used to carry out the analysis; and the third part describes the gaps between the use of SNA in the AEC industry and the dimensions of interactions in a work team with the objective of proposing the application of SNA to other dimensions of interaction and analysis.

## Dimensions of interaction in a work team

For a work team to be effective, several conditions associated with a compelling direction, an enabling structure, a supportive organizational context and team coaching must be present; teamwork has multiple dimensions that must be evaluated (Valentine et al. 2015). Specifically, some key performance elements of construction project design teams are as follows: the encouragement of collaboration, creation of a unique and challenging project, involvement of the team members in planning, commitment to the team, acceleration of the team-building process, commitment of the members to the goal, a sense of purpose, dedication to the time and effort required to form a team, opportunity for the team members to become familiar with each other and the project, increased collaboration in the whole project, identification of the design team member roles and trust between the team members (Svalestuen et al. 2015).

Several authors have reported a set of factors or dimensions that directly impact the effectiveness of a team in the AEC industry, and many of these factors are related to the concept of interaction. This review found that one of the first studies on teamwork in the

AEC industry was that of Baiden et al. (2006), who defined a list of 10 dimensions for an integrated work team. The list was recently updated in the literature with the following inclusion criteria: articles from the last five years; categories for the Web of Science including “multidisciplinary engineering”, “civil engineering”, “construction or building technology” and “architecture”; development of different dimensions or elements of teamwork and not only the generic concept; and papers in the AEC industry professional context. Educational papers were excluded from this study. Thus, the list was updated to 13 dimensions with the literature review of 17 papers from 2014 to 2019. Table 1 presents an updated list of dimensions that affect the integration of a work team.

Table 1: Dimensions that impact a work team – percentage of paper that mentions it

| Dimensions | Description | % |
|---|---|---|
| Single team focus and objectives | All members have the same focus and work together towards team objectives (Baiden et al. 2006). | 100.00% |
| Seamless operation with no organization defined boundaries; coordination | Members form a new single project team with no individual member identity or boundaries, so there is a high degree of coordination among team members (Baiden et al. 2006). | 70.59% |
| Mutually beneficial outcomes | Achievement project goals that benefits all members | 47.06% |
| Openly accessible design and construction information | Increased time and cost predictability, through a transparent information policy shared among all members(Baiden et al. 2006). | 52.94% |
| Unrestricted cross-sharing of information | Availability and access to all project information to all parties involved in the project (Baiden et al. 2006). | 64.71% |
| Team flexibility and responsiveness to change | Require personnel join and leave the project team as their skills are no longer required or are needed (Baiden et al. 2006). | 17.65% |
| Creation of single and co-located teams | A single project team with all members located together in a common office (Baiden et al. 2006). | 47.06% |
| Equal opportunity for project | Consultation of members for contribution at all phases of project before decisions are made, i.e. all members collaborate (Baiden et al. 2006). | 58.82% |

| | | |
|---|---|---|
| Equitable team relationships and respect for all, trust and team chemistry | All members are treated as having equal and significant professional capability needed on the project (Baiden et al. 2006). | 64.71% |
| No blame culture | Collective identification and resolution of problems and collective responsibility for all project outcomes (Baiden et al. 2006). | 58.82% |
| Learning among team members | Team members learn from each other about technologies, methodologies and ways of working (Herrera et al. 2018). | 41.18% |
| Contract models or type of project delivery | To have a relational type of contracting system, where collaboration and integration of the project is promoted from early stages (Svalestuen et al. 2015). | 52.94% |
| Identification of the design team members' roles | All team members should have a clear understanding of their roles and responsibilities, and that of other team members (Savolainen et al. 2018). | 29.41% |

From these dimensions, the following dimensions of interaction can be deduced: transfer of information, linking of trust, coordination and planning, and collaboration and learning among team members. Undoubtedly, one of the most characteristic elements of an effective team is associated with having and working for a common goal; however, this factor, along with others, is not considered an interaction among team members. Therefore, the researchers considered only the dimensions that can be represented as an interaction between two or more people.

Typically, design teams adopt a goal-oriented approach by prioritizing and sharing only what is necessary; therefore, they exhibit a distributed knowledge system, in which they rely on each person properly knowing his or her role and on the concept that not everyone needs to know everything to succeed in a design project (Kleinsmann et al. 2012). The collaborative approach of team members is accompanied by systematic discussion and negotiation (Kleinsmann et al. 2012); thus, a shared understanding among all the team members when they are making agreements is essential (Cash et al. 2017). This shared understanding implies that the interaction of team members must be based on continuous cycles of commitment (Viana et al. 2011).

Commitment cycles are understood as a network of commitments among the people in a team (Flores, 2015). The commitments network approach emphasizes what people do while communicating, how the language is used to create a common reality and how activities are coordinated through language (Viana et al. 2011). Basic elements of this perspective are speech acts, which are a set of rules for systematizing commitment management (Searle 1969). According to Medina-Mora et al. (1992), one of the methods to model commitment management is the action workflow. These researchers state that two people are required to establish a commitment (a customer and a performer). The commitment cycle has four phases: (1) request/proposal, (2) negotiate/agreement, (3) declare compliance/performance and (4) declare acceptance/satisfaction (Medina-Mora et al. 1992). The first phase is the request of a requirement from a customer (internal or external) to someone who will perform the request. The second phase is the negotiation and definition of satisfactory conditions and delivery dates between the customer and the performer. The third phase is the execution of the requirement according to the negotiated conditions and declaration of its completion (Searle 1969).

Finally, the fourth stage is the assessment, declaration of acceptance and feedback from the customer (Searle 1969). The structure is defined by the language acts through which people coordinate, not the action performed by individuals to meet the conditions of satisfaction. Therefore, each of these speech acts can be considered specific dimensions of interactions that are interconnected (Flores, 2015).

Consequently, from the literature review, dimensions of interaction can be defined from a traditional perspective and from a commitment management perspective. The traditional dimensions of interaction identified were the following: transfer of information, linking of trust, coordination, and collaboration and learning among team members. The dimensions of interaction associated with commitment management are associated with each of the speech acts, i.e., requirements, negotiation, declaration of completion and declaration of acceptance (Long and Arroyo 2018). In addition, a basic element for all work teams is that all members know each other's roles and responsibilities.

## SNA experiences in the AEC industry

SNA uses sociograms to represent relationships between different people (Hickethier et al. 2013). People are represented by nodes, and the line between them constitutes a connection or edge. Each network can be represented graphically with a sociogram and with mathematical metrics, which can be classified into organizational or network metrics and individual or node metrics (Al Hattab and Hamzeh 2015) (Table 2).

Table 2: SNA Metrics

| Type | Metric | Definition |
|---|---|---|
| Node | Degree | How many other nodes a node is connected to (Alarcón et al. 2013) |
| | Betweenness | How many pairs of individuals are connected through a node with the least number of steps: brokerage role (Hickethier et al. 2013) |
| | Closeness | How close a node is to other nodes: depends on the shortest average length (Al Hattab and Hamzeh 2015) |
| Network | Density | How many actual links exist between nodes divided by the number of total possible links in the network (Alarcón et al. 2013) |
| | Mean Degree | How many other nodes a node is connected to, on average |

| | | |
|---|---|---|
| | | (Alarcón et al. 2013) |
| | Clustering | How clustered groups of people are compared to the rest of the network, the existence of closed triads and small communities (Hickethier et al. 2013) |
| | Average path length | How many steps, on average, nodes require to reach each other (Al Hattab and Hamzeh 2015) |
| | Diameter | How many steps, nodes require to reach each other (maximum) (Al Hattab and Hamzeh 2015) |
| | Modularity | How dense are the connections between nodes within groups compared to nodes with another group (Hickethier et al. 2013) |

Another interesting indicator to assess project teams is the number of connected components. Components are sets of nodes that are linked to one another through continuous chains of connections; a connected network simply comprises a single component (Scott 2017). The members of a component can communicate with one another, either directly or through chains of intermediaries. On the other hand, isolated nodes have no such opportunities; the number of connected components can be taken as an indication of the opportunities and obstacles to communication or the transfer of resources in the associated network (Scott 2017).

Social networks can be characterized as directed or undirected links. Undirected links occur when two people have a bidirectional interaction obligation; in contrast, directed links imply that the interaction flows from person A to person B. Therefore, directed links can be unidirectional or bidirectional (Hoppe and Reinelt 2010) depending on the dimension of interaction being analyzed. Except for their degree, the metrics presented in Table 2 do not change based on whether the links are directed or undirected. In directed networks, there is a degree of input or indegree (number of connections reaching the node) and a degree of output or outdegree (number of connections leaving the node); the metric degree is obtained as the sum of both (Scott 2017). In addition, connected components can be searched for in both undirected and directed graphs. However, there are important differences between the two situations (Marin and Wellman 2011).

In the case of directed graphs, two distinct types of components can be identified: strong components and weak components. A strong component is one in which the lines that make up the paths are aligned in a continuous chain without any change of direction; thus, it represents a set of agents among which such resources can easily and freely flow (Scott 2017). On the other hand, in a weak component, it can be assumed that the mere presence of a relationship, regardless of its direction, allows some possibility for communication; thus, weakly connected components represent semipaths in the network (Scott 2017). In the case of undirected graphs, because no directions are attached to the lines, all paths constitute acceptable connections (Scott 2017).

The relevant characteristics to carry out an SNA are the following: type of organization, dimension of interaction and metrics. Table 3 exemplifies each of these characteristics from prior research that used SNA in AEC organizations. All these studies present case studies in which an SNA was carried out, with the exception of the work of Al Hattab and Hamzeh (2015), who present a theoretical analysis of an organization. In all the case studies presented in Table 3, data capture is carried out through surveys (paper or online) conducted on the participants of the analysis (Flores et al. 2014; Herrera et al. 2018); therefore, it must be assumed that there may be some subjectivity in the input data of the SNA.

Table 3: SNA experiences in the AEC industry

| Source | Type of organization | Types of interactions | Metrics |
|---|---|---|---|
| (Hickethier et al. 2013) | Design team (complex project) | Information flow | Clustering; centrality |
| (Alarcón et al. 2013) | Mining companies | Interaction; information flow; problem solving; planning; trust | Mean degree; diameter; density; average path length |
| (Priven and Sacks 2013) | Construction complex projects | Information flow; trust | Density |
| (Flores et al. 2014) | Construction Companies | Interaction; information flow; problem solving; planning; innovation; trust | Mean degree; diameter; density; average path length |
| (Al Hattab and Hamzeh 2015) | Design teams | Interaction; information flow | Density; average path length; modularity; clustering; centrality |
| (Segarra et al. 2017) | Architecture offices | Interaction; information flow; innovation | Mean degree; density; average path length |
| (Schröpfer et al. 2017) | Construction complex projects | Knowledge transfer | Density, degree, betweenness |
| (Herrera et al. 2018) | Designs team (complex projects) | Interaction; information flow; planning; learning; trust | Density |
| (Castillo et al., 2018) | Construction companies | Personal confidence, innovation development, interaction, relevant information exchange, planning and problem solving | Diameter, density, average path length, and average degree |

From the examples presented in the AEC industry (Table 3), the networks most frequently measured are those of interaction and information flow, and the metrics most analyzed are those linked to the organization (density, diameter, average path length) and not to the people (degree, centrality, betweenness). In addition, the analyses are performed on companies (Alarcón et al. 2013; Flores et al. 2014; Segarra et al. 2017) or complex projects (Hickethier et al. 2013; Priven and Sacks 2013; Schröpfer et al. 2017), where the number of participants is high (50 people or more). Furthermore, in these studies, it is not specified whether the links of the networks are directed or undirected, with the exception of Al Hattab and Hamzeh (2015), who clarify that the interaction has undirected links. In addition, none of these studies include a study carried out on the number of connected components.

## Gaps in SNA in the AEC industry

Two perspectives are identified within the dimensions of interaction: traditional interaction and commitment management. According to the experiences found regarding the use of SNA in the AEC industry, there is evidence of evaluations of dimensions of traditional interaction in this industry, for example, interaction, information flow, problem solving, planning, innovation, trust and learning. However, interactions such as knowledge of roles and collaboration are not explicitly included because these elements have been broadly studied as key elements in the effectiveness of a work team (Baiden et al. 2006; Savolainen et al. 2018; Svalestuen et al. 2015). In addition, Kereri and Harper (2019) recently proposed to use SNA for the evaluation of collaboration in construction project teams. Furthermore, based on similar experiences in the AEC industry, there is no evidence of interaction assessments associated with the perspective of commitment management, although this element is key to a shared understanding in multidisciplinary teams in which discussion and negotiation are common (Kleinsmann et al. 2012).

For each dimension of interaction, an analysis of the social network can be performed; therefore, for each interaction, the links must be defined as directed or undirected, according to the nature of the interaction (Hoppe and Reinelt 2010). According to the SNA experiences in the AEC industry, this definition is not explicit; however, it is fundamental to the analysis of metrics and input data filtering because some metric calculations are affected depending on the characteristics of the link (Scott 2017).

Because data capture is conducted through a survey of project team members, there will always be some amount of subjectivity of the input data; therefore, an analysis of the coherence of the input data must be performed before the SNA (Cisterna 2017). This coherence analysis can be performed in undirected networks in which, theoretically, there is a correspondence between the responses of the people involved, so that if person A wishes to interact with person B, then person B must indicate the same (Cisterna 2017).

Although there are metrics for SNA that have mathematical interpretations, a practical interpretation should be provided for the construction project design teams (less than 50 people) (Castillo et al. 2018a). In addition, new metrics should be proposed for the dimensions of interaction associated with commitment management because these networks interact with each other as part of a cycle, even though there are no SNA metrics linking two or more networks. The definition of the link types (directed or undirected), the coherence analysis to validate the input data and the definition of new dimensions of interaction, and their metrics and interpretation must be included in the existing SNA methodology (e.g., Alarcón et al. 2013; Flores et al. 2014).

## PROPOSAL FOR A NETWORK EVALUATION METHOD: METRICS AND SOCIOGRAMS

The objective of this evaluation method is to capture data from different dimensions of interaction in construction project design teams. To develop the method, the following steps were followed: (1) definition of the interaction dimensions and description and definition of the link type for each interaction, (2) definition of the participants involved in the data capture and the data capture method, (3) definition of the questions (and type of answer) to capture information for each interaction, (4) definition and analysis of the metrics and sociograms for each dimension of interaction and validation data criteria and (5) data collection and analysis.

Based on the literature review, the dimensions of interaction to be assessed were defined. Tables 4 and 5 present the description for each dimension of interaction and the type of link associated with each from the perspective of traditional interaction and commitment management, respectively. The description of each dimension of interaction and the type of link (directed or undirected) was determined by a multidisciplinary team of professionals. This team included engineers, builders, researchers, architects and linguists; all with experience in SNA and teamwork assessment in the AEC industry.

Table 4: Descriptions of types of interactions – traditional

| **Type of interaction** | **Description** | **Type of link** | **Source** |
|---|---|---|---|
| Knowledge of roles and responsibilities | When person A knows the role and responsibility of person B, a one-way link is created between the two people. This network is fundamental, since if the link does not exist, it is difficult to make another type of interaction. | Directed | Proposal |
| Global interaction | Refers to any type of interaction between two people, these include telephone conversations, mail exchanges, conversations or business meetings. | Undirected | (Alarcón et al. 2013) |
| Relevant work information | Relevant work information is that flow where person A sends necessary information to person B that adds value to the project but is not openly available. | Directed | (Castillo et al., 2018) |
| Collaboration | Collaboration refers to the act of joint work between two or more people. It is considered that working together implies working with another person on the same | Undirected | Proposal |

| | | | |
|---|---|---|---|
| | task and at the same time, either in person or virtually. | | |
| Planning and problem solving | Collaborative planning and problem solving refer to the joint act of two or more people to define and redefine tasks, schedules, resources, costs, risks, etc. | Undirected | (Castillo et al., 2018b) |
| Trust | When a person A trusts the work of a person B, a one-way bond of trust between A-B is created. | Directed | (Priven and Sacks 2013) |
| Learning | When a person A learns something new from a person B, a learning link between A-B is created. What is learned can be something technical related to knowledge, some skill or competence, or even an attitude at work. | Undirected | (Herrera et al. 2018) |

Table 5: Descriptions of types of interactions – commitment management

| **Type of interaction** | **Description** | **Type of link** | **Source** |
|---|---|---|---|
| Request for requirement | The speaker (customer) is asking a potential performer for action around a requirement. | Directed | (Long and Arroyo 2018) |
| Requirement negotiation | The customer and the performer clarify the requirement and define conditions of satisfaction, based on time, cost and performance. | Undirected | (Viana et al. 2011) |
| Declaration of compliance | The performer reports facts and is prepared to offer evidence about the compliance of the requirement. | Directed | (Long and Arroyo 2018) |
| Declaration of satisfaction | The customer reports a level of satisfaction and feedback about the compliance of the requirement. | Directed | (Long and Arroyo 2018) |

The people involved in the analysis are all those involved in the design phase, which may vary depending on the nature of the project. The roles that may be stakeholders are the project manager, architect, structural engineer, client, client representative, geotechnical engineer, MEP engineer, BIM manager, planning engineer, general contractor and others (Al Hattab and Hamzeh 2015). The interaction data capture tool is a survey that must be answered by those involved in the design phase. Because these stakeholders typically do not work in the same place, it is easier to use an online survey server. It is recommended to have a meeting with the project manager to discuss the scope and benefits of the analysis and to list the participants and their roles before sending the survey to all the participants.

The data capture survey has a question for each dimension of interaction. For each question, the respondents are asked to identify the other people and the dimension of interaction they had in a defined period of time; this time depends on the context of the project being assessed and the purpose of the assessment, e.g., if a design team wants to evaluate only the detailed design phase, then the period of time should correspond to the duration of this phase of the project. In this case, the researchers used "the last twelve weeks", based on previous experiences (Segarra et al. 2017). In addition, examples are provided to ensure the question is understood. There are three types of answer for each question: yes/no per person, number of times per person and frequency per person. Table 6 shows the answers associated with each type of network.

Table 6. Types of response for each type of interaction

| **Type of interaction** | **Response** |
|---|---|
| Knowledge of roles and responsibilities<br>Global Interaction<br>Trust<br>Learning | Yes/No |
| Relevant work information<br>Collaboration<br>Planning and problem solving | Always (1 or more times per day) / Often (1 to 4 times per week) / Sometimes (1 to 3 times per month) / Never (less than 1 time per month) |
| Request for requirement | Yes/No |
| Requirement negotiation<br>Declaration of | Always (over 80% of the time) / Often (60% to 80% of the time) / Sometimes (20% to 60% of the time) / Never (less 20% |

| | |
|---|---|
| compliance<br>Declaration of satisfaction | of the time) |

After capturing the data, it is necessary to validate their reliability. Therefore, a coherence analysis is carried out on the undirected network "global interaction". Coherence analysis in undirected networks differentiates between valid and invalid interactions: if person A wishes to interact with person B, and person B wishes to interact with person A, then the interaction is valid; if person A wishes to interact with person B, and person B does not wish to interact with person A, then the interaction is invalid. Therefore, it is possible to calculate a percentage of valid connections (PVC) as the proportion between the valid connections and the total connections (valid and invalid). It is recommended to define a sufficiency condition or limit for this percentage, which ensures that the input data are reliable and thus allows the SNA to continue (PVC must be defined by the assessment team). The PVC has been obtained in other studies, and these values varied between 50% and 90% (Cisterna 2017); however, there are no studies that provide information on the definition of the PVC limit. In this case, the researchers used a pragmatic vision based on general rules such as the concept of Pareto, which considers 80% predominant to explain a phenomenon (Craft and Leake 2002), or such a typical confidence level value (80%) used in risk analysis of the construction industry (Alarcón et al. 2011). Therefore, the team defined a limit percentage of 80% of valid connections for the data to be reliable; if the percentage was less than this condition, it may have meant that the question was understood differently by the different survey participants.

If the validation of input data has a positive result, then the networks are represented through an adjacency matrix. This matrix represents the link between pairs of people through a weight; the weight depends on the type of response. Ones and zeros correspond to responses of yes and no, respectively, and for answers of frequency, "never" is scored with a zero, and the different levels are classified either in an ascending scale (1, 2, 3) or with the value of 1 for all responses other than "never". In directed networks, it does not matter whether the links are unidirectional or bidirectional, but in undirected networks, there must be a unique link between person A and person B. Therefore, it is necessary to make a prior filter eliminating all the invalid interactions. Then, the adjacency matrix must be loaded on to software that allows SNA, which provides metrics and sociograms for each dimension of interaction.

The sociogram analysis makes it possible to visually identify people or groups of people who are disconnected or isolated, central people and people who serve as brokers or bridges. It is interesting to analyze the changes generated in pairs or groups of networks: knowledge of roles–global interaction, global interaction–work information, collaboration–planning, trust–learning and all commitment management networks. To perform metrics analysis, it is not necessary to analyze all the social network metrics in each type of network; thus, depending on the network, the metrics to be analyzed are selected. Furthermore, in some cases, it is interesting to analyze metrics with data from different networks. Table 7 presents the list of metrics for each network. In the next section, an interpretation of each metric is performed using a pilot project.

To apply the proposed method, the activities outlined in Fig. 2 should be carried out. For the creation of the survey, it is first necessary to establish the initial conditions, such as (1) the definition of the interaction time period (e.g., the 12 weeks used in this pilot project); (2) definition of the data collection method, which, for noncollocated teams, is usually an online survey server or an in-person survey; (3) definition of the study participants (client, architect, specialist engineers, project manager, etc.); (4) definition of the limit for the PVC for validation of the reliability of the answers obtained; and (5) selection of the software to carry out the SNA (there are several free software packages such as Gephi and iGraph). Second, the survey should be created considering all the previous information, the descriptions of the interaction dimensions (Tables 4 and 5) and the questions and answers for the evaluation (Table 6). Third, the survey should be sent to the defined participants and the data collected; for small teams, it is recommended that 100% of the defined participants respond. Then, with the information collected, the data are processed using the selected software, according to the type of link of each interaction dimension, directed or undirected (information available in Tables 4 and 5). Then, the metrics are calculated according to the definitions in Table 7, and the PVC limit criterion is reviewed to determine whether the analysis can continue. If the PVC criterion is satisfied, then the sociograms are created and the analysis proceeds. Finally, the analysis consists of two parts: an analysis of the metrics and sociograms according to the project context, which can be done between the assessor and project manager, and a comparative analysis with other experiences in the AEC industry reported in the literature (Table 3).

Table 7. Proposed metric for each network

<table>
<tr><th>Type of network</th><th>Metrics</th></tr>
<tr><td>Knowledge of roles and responsibilities</td><td>In-degree of each node; Mean in-degree of the network</td></tr>
<tr><td>Global interaction</td><td>Degree of each node; Mean and range degree of the network; Network density; # connected components</td></tr>
<tr><td>Relevant work information</td><td rowspan="2">Percentage of bidirectional links; In-degree and out-degree of each node; Mean and range degree of the network; Network density; # weakly and # strongly connected components</td></tr>
<tr><td>Learning</td></tr>
<tr><td>Collaboration</td><td rowspan="2">Percentage of bidirectional links; Degree of each node; Mean and range degree of the network; Network density; # connected components</td></tr>
<tr><td>Planning and problem solving</td></tr>
<tr><td>Trust</td><td># links trust network / # links knowledge of roles network</td></tr>
</table>

| | |
|---|---|
| Request for requirement | In-degree and out-degree of each node and the sum |
| Requirement negotiation | Negotiated links / (requirements links / 2) |
| Declaration of compliance | Compliance declaration links / requirements links |
| Declaration of satisfaction | Satisfaction declaration links / requirements links |

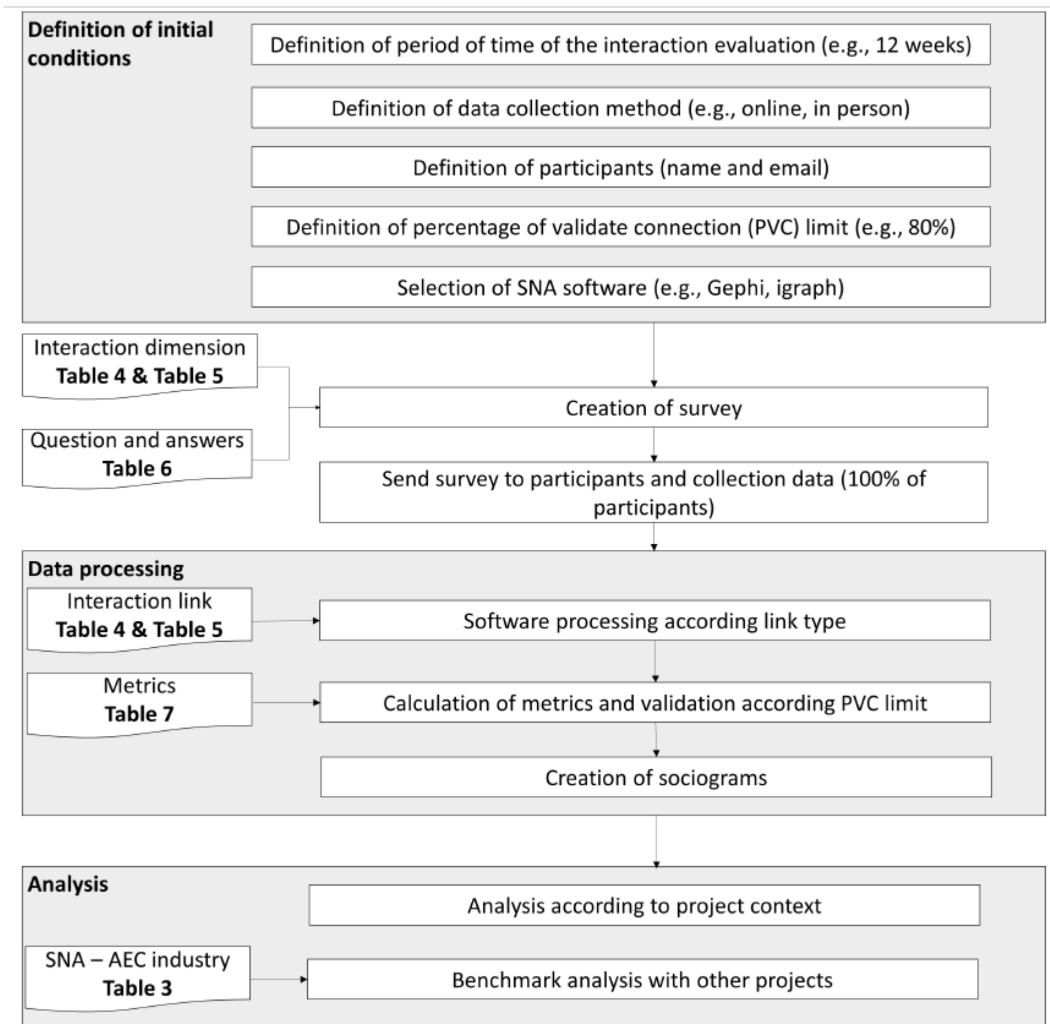


**Fig. 2.** Proposed method for understanding interaction in design teams

## PILOT PROJECT: EVALUATION AND ANALYSIS

A pilot project was used to exemplify the use of the tool. The pilot project involved the design team of a project to build a 28,500 $m^2$ residential building consisting of 22 floors and two sublevels, located in the city of Santiago, Chile. This project had two important characteristics: (1) the client was the same company as the builder, which led to the expectation of a global vision for the project in its design and construction phases; and (2) all the specialties of the design phase were contracted to different companies, which was the opposite of a collocated situation.

During the design, 12 people participated in the following roles: project manager (PM), client representative (CR), architect (A), geotechnical engineer (GE), structural designer (SD), structural reviewer (SR), electrical specialist (E), plumbing specialist (P), gas specialist (G), pool designer (PD), irrigation designer (ID) and landscape designer (LD). The PM and CR were part of the client's company, and the rest of the personnel were from different companies, so much of the interaction was through emails and phone calls. In this project, only the architecture office worked on a BIM platform and the specialties in a traditional way (2D drawing and specialized analysis software) (Rojas et al. 2019), so it was not possible to capture the interaction data that were logged in the BIM environments. All the stakeholders answered the online survey to provide data about the team interaction. The analysis of the consistency of the responses of the global interaction network gave a percentage of valid interaction of 85.71%; thus, the input data were reliable for performing the SNA, according to the 80% limit proposed by the research team.

Currently, there are no studies that define the ideal range for the metrics; however, a comparative analysis was performed using the values obtained from projects of similar size (number of participants). Because a project is a temporary organization in which all the participants have the common objective of carrying out the design, it is expected that all the participants know their roles, and the mean degree must be close to the number of participants minus one. In the pilot project, the average grade was 4.33, i.e., one person knew the role of approximately four other people. Fig. 3 (left) shows the role knowledge network, in which the size of the nodes is proportional to the level of knowledge of the entire organization toward that node (indegree). Therefore, in this organization, the knowledge toward the project manager was at the first level, with the area of architecture and structures at the second level and other design specialties at the third level. In a small team such as the one in this project, one would expect all the specialists to know the roles and responsibilities of the others (Svalestuen et al. 2015). However, on average in this project, each person knew the role of only one-third of the team.

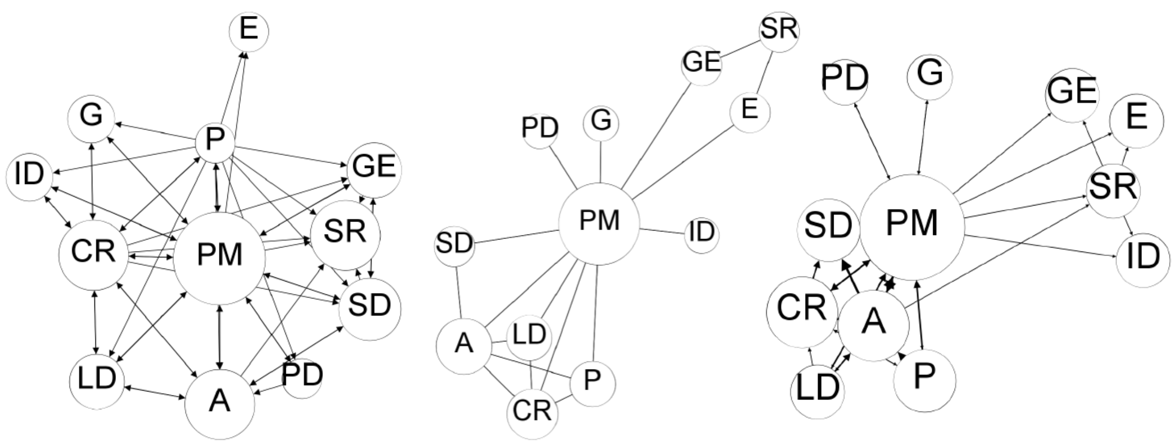


**Fig. 3.** Knowledge of roles network (left)/ Global interaction network (middle)/ Relevant work information (right)

In the global interaction network (Fig. 3 center), all the nonreciprocal connections first needed to be eliminated because it was an undirected network. The density of this network was 0.273 with a mean degree of 3, i.e., an average person connected with three others. However, there was also a high variability (range equal to 9). Thus, the lowest degree was

1, and the highest degree was 10. This density value was low compared to the value obtained in the airport design teams in which the density of the interaction network was approximately 0.5 (Herrera et al. 2018). This phenomenon may have been due to the context of the typology of the project, e.g., in architecture offices the density varies between 0.4 and 0.5 in teams of this size (Segarra et al. 2017), or in construction teams on the worksite, the density varies between 0.4 and 0.7 (Priven and Sacks 2013). The project manager is the node with the highest number of connections, and from this node there is a connected group (number of connected components equal to 1). In this work, the project manager was an important node of articulation, because if it was taken out of the network, then the number of connected components increased to five, leading to a team with two or more subgroups (in this case five), in which the interaction between the specialists and other team members might be difficult. Note that in this case, the global interaction network is a subnetwork of the role knowledge network, i.e., for people who can interact, first the roles of each of the team participants must be presented and defined. Therefore, the kick-off meetings are essential to initiate the expected interaction between the different professionals (Koo et al. 2013), and they should be utilized in all project teams.

Fig. 3 (right) shows the relevant work information network in the pilot project, and the thickness of the arrow represents the frequency of the information flow, i.e., the network. A thicker arrow shows a higher frequency of information. The reciprocal connections, which constituted 67.65% of the information network, included the participation of the client's representative, the project manager, the architect, the structural designer and a few specialist designers. The density was 0.258, which was low compared to the value obtained in airport design teams in which the density of the interaction network was approximately 0.4 (Herrera et al. 2018). Moreover, in larger design teams (between 40 and 60 people) the integrated density was approximately 0.1 (Al Hattab and Hamzeh 2015). Thus, a team four or five times larger than the pilot project only reduced the density by half. The mean indegree was 2.83, and its range was 7; the mean outdegree was 2.830, and its range was 10. Therefore, there was high variability regarding the sharing of work information, which demonstrated an inhomogeneous flow of information that focused on the project manager and the architect. There was one weakly connected component and five strongly connected components. Thus, the network was weakly connected, and, as in the interaction network, it was strongly dependent on the project manager, which was contrary to the goals of lean management practices regarding the transparency of information (Wesz et al. 2018) and was greater among the specialists through technology (American Institute of Architects California Council 2007).

Collaboration and planning are strongly related to problem-solving networks because planning can be a type of collaboration. Therefore, the planning network should be a subnet of the collaboration network. Both types of networks have undirected links, and all invalid connections must first be removed. In the case study, both networks had similar characteristics, which was evidenced by their indicators. The proportion of reciprocal connections was 90.32% in both cases, which explained the high reliability of the input data. Additionally, in both networks, there were two disconnected people (three related components), meaning there was no collaborative planning. Finally, the collaboration and planning had a density of 0.212 and a mean degree of 2.330. Thus, there were 10 people who were connected; however, for most of the opportunities the project manager was the intermediary (Fig. 4). Therefore, in this project, there were no planning activities and collaborative work because the planning was carried out in meetings of two or three people and not among the 12 people who made up the work team. Current technologies and design methodologies support collaborative work and planning among the specialists to achieve greater understanding and time efficiency in projects, which produces better results in the designed product (Rahmawati et al. 2014).

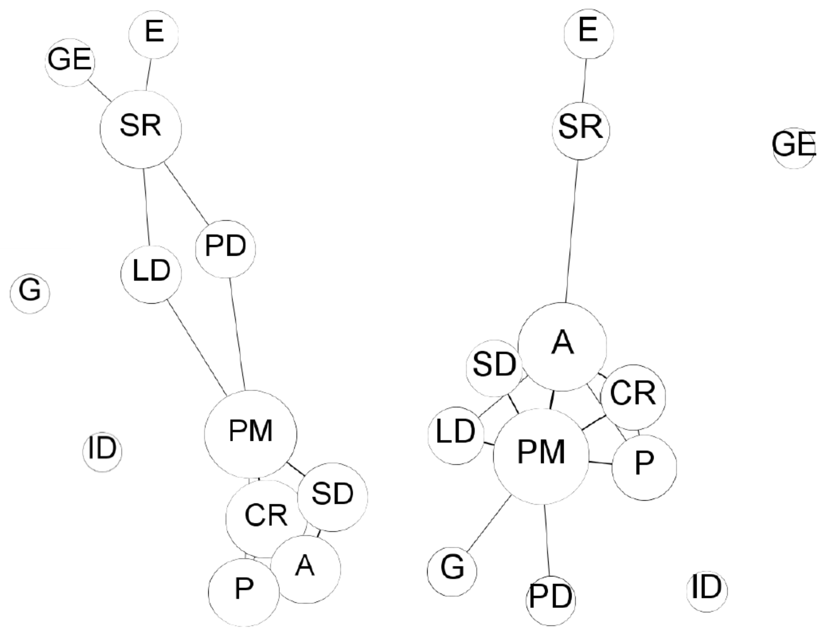


**Fig. 4.** Collaboration network (left) / Planning and problem-solving network (right)

The level of trust between members of a team is fundamental for a team to be effective (Austin et al. 2015). In the pilot project, the trust network was created (Fig. 5). In this project, there were 36 connections of trust and 52 connections of knowledge of roles, which meant that the relative level of trust was 0.690 in the network and that there was a high degree of trust between the people who knew each other. However, note that the level of knowledge of roles in this organization was low (density 0.394); of the four people a team member knew, he or she trusted two or three, on average. Therefore, in this team, there was no problem of trust but rather of knowledge of the team and greater collaboration. However, there was no evidence that an increase in the links of knowledge would result in an increase in the network of trust, but it is known that through collaboration and collaborative planning, trust can be strengthened (Flores et al. 2014). To learn from another person, it is necessary to trust that person (Karp et al. 2019); therefore, the learning network is a subnet of the trusted network (Herrera et al. 2018). In the case study, a small learning network was obtained, in which only 9 of the 12 stakeholders of the project participated and in which their level of connectivity was weak because their mean degree was 1.083, their density was 0.247 and the percentage of reciprocal connections was 7.69%. Thus, an average person learned from only one person, although there was an opportunity to learn from 11 others. Therefore, in this project, there was an important growth gap in the learning network, given that organizations need to be constantly learning, especially with the implementation of new technologies (Wong et al. 2014).

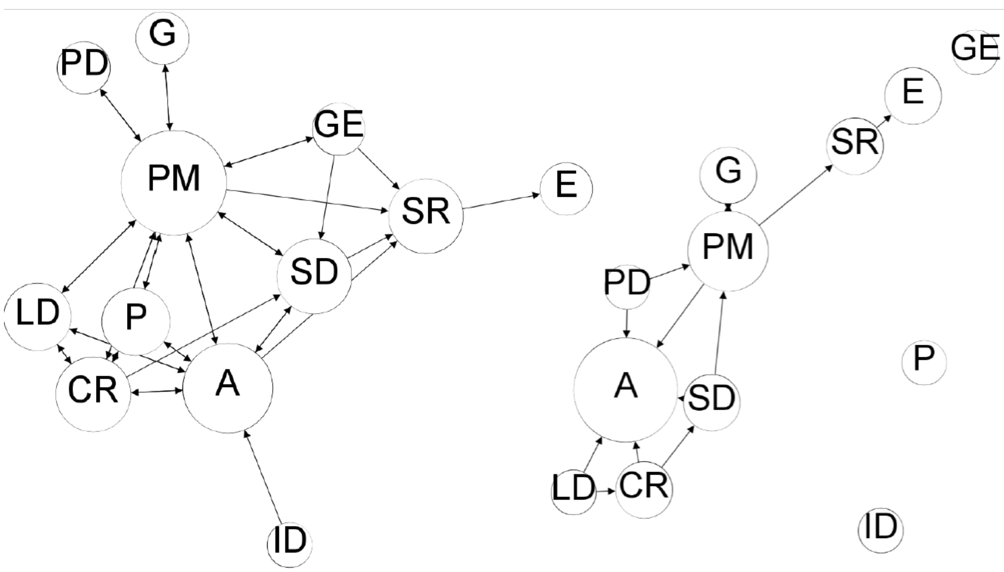


**Fig. 5.** Trust network (left) / Learning network (right)

The multidisciplinary design process involves continuous discussions and negotiations among the participants, so it is essential to manage the commitments correctly (Cash et al. 2017). A network was created to allow for each step to have a reliable commitment (Fig. 6). The request for requirements network is a measure of the requests made by the people involved for some task or document. The indegree of person A represents the number of people who request something from person A and not the number of requirements that person A has, and the outdegree of person A represents the number of people to whom person A is sending a request. In the pilot project, the sum of the input degrees of each node was 27, which meant that there were 27 connections between people, of which 7 were unidirectional and 20 were bidirectional. In the negotiation requirements network, the connections can be visualized as a negotiation between those involved. With this information, the percentage of negotiated requirements in the pilot project was calculated to be 51.85%.

After a request, the requirements correspond to a declaration of completion. In the pilot project, the percentage of declaration of compliance was 59.25%, and when only the negotiated requirements were reviewed, the percentage reached 100%. Therefore, the discussion generated in the negotiation required a "following compliance declaration". The percentage of declarations of acceptance was 62.96%; the customer declared satisfaction in approximately 6 out of 10 requirements. For cases in which the only declared requirement was fulfillment, the percentage increased to 93.75%. This result confirms the need to include these four steps in the process of creating the correct management commitment requirements and to ensure a shared understanding among the participants.

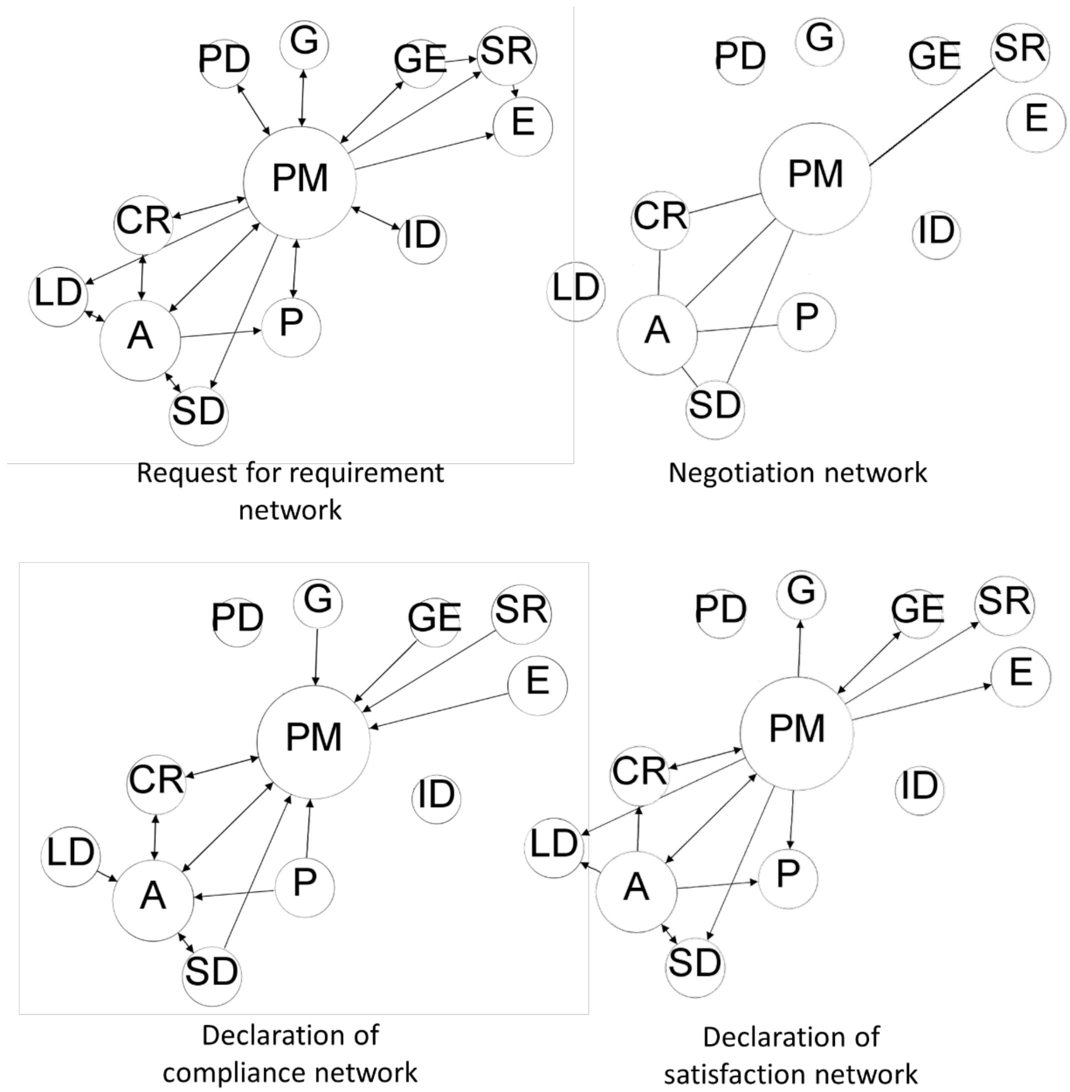


**Fig. 6.** Commitment management networks

To summarize, in the pilot project, weak interactions were identified that were strongly centered on the project manager, with low interactions between different designers. This low interaction was initially caused by a lack of knowledge of the roles of the members of the team, a critical element in the project, in which each designer was from a different company. Thus, the kick-off meeting was fundamental in this project (Koo et al. 2013). Regarding commitment management, a low level of negotiation of requirements (clarifying deadlines, resources, scope, etc.) was identified, which affected the declarations of compliance and satisfaction without achieving the cycle for correct commitment management. Therefore, there was no continuous cycle of commitments affecting the shared understanding among the team members (Viana et al. 2011), which may have affected the design process, generating more rework or other wastes (Cash et al. 2017).

The application of the method involves three major efforts: (1) obtain answers from all the participants of the survey, (2) process the data with software, and (3) analyze the data and understand the context. To obtain answers from all the participants of the survey, the evaluator must have an internal organizational partner to facilitate the process. In addition, the people should understand the questions equally, so the coherence analysis is fundamental. In the pilot project, a PVC of over 80% was achieved, demonstrating that there was a good understanding of the questions by the respondents. Additionally, the creation of the questions for each type of interaction should be done with an understanding of the industry context and the language used by the design team being evaluated. In this case, the survey was created by a multidisciplinary team of engineers, architects, builders, consultants, and linguists, which allowed a broad and contextualized view of the characteristics of a design team. Then, to process and analyze the data, the evaluator must understand that, with this method, the results of the analysis give no answers but reveal where to ask questions (Alarcón et al. 2013), so it is essential to understand the context of the organization. There are two main limitations to the application of this method: first, there is no willingness on the part of the work team to respond judiciously to the survey; and second, the study has a punitive purpose. These limitations affect the objective of understanding the design team interaction that would allow it to improve and strengthen the channels in which the team interacts. In future studies, new types of interaction and new metrics can be added to analyze and understand the interactions of design teams in construction projects. In addition, assessments could be done in conjunction with other techniques for evaluating interaction and teamwork.

## CONCLUSIONS

For a design team to be successful, the design participants must have high levels of interaction. To evaluate the interaction, a method was proposed to understand the interactions in this type of work team using SNA as a tool and evaluating the interaction from a multidimensional point of view. The key dimensions of interaction in a design team were identified and grouped into two groups: traditional interaction and commitment management. The latter group is fundamental in design teams because there are instances of systematic discussion and negotiation that oblige the team to have a shared understanding of the actions to be followed. In addition, this was the first time that speech acts were modeled using SNA. The SNA is a tool that allows global and individual analysis in a visual format and with mathematical indicators. Each dimension of interaction is represented as a network and may have an individual analysis; however, it is also necessary to perform an analysis between two or more networks. The proposed method has the following practical applications: (a) understanding the interactions of the design team from several perspectives; (b) taking corrective actions to improve the interaction to make it more efficient and less dependent on a single person; (c) recognizing the causes that generate a shared misunderstanding among the members of the team; and (d) taking actions in this matter, such as generating knowledge of roles, meetings for collective planning, and opportunities for collaborative work. These benefits can improve the common understanding of project requirements, reduce waste and increase the value of the design process. The application of the method requires that all the members of the design team respond to the survey; therefore, there must be a commitment from the organization that is being assessed. In addition, respondents should equally understand the questions, so the evaluation team should write the questions in context and verify the PVC limit through coherence analysis. In addition, the evaluation team and the design team should understand this method as a tool for continuous improvement and not as a punitive mechanism.

There are some limitations to this method. The tool is used for evaluation over time; therefore, comparisons should be made between projects with similar levels of progress. In addition, the researchers only assessed a pilot project with the SNA tool. For future research, it is recommended to perform assessments with this method on a large number of design teams with different compositions, e.g., collocated/noncollocated teams, different numbers of companies, different management systems and different technology application levels (BIM environments), to understand how the context, management and technology affects interactions between team members. In addition, it would be interesting to evaluate new dimensions of interaction, study new metrics for small networks and analyze their quality and evaluate the metrics between different networks. Furthermore, in projects that work in BIM environments, it would be interesting to contrast the networks obtained from the log files and the networks obtained with the proposed method.

## DATA AVAILABILITY STATEMENT

Some or all data, models, or code used during the study were provided by a third party (list items). Direct requests for these materials may be made to the provider as indicated in the Acknowledgements

## ACKNOWLEDGEMENTS

The writers would like to acknowledge the help and support provided by GEPUC and GEPRO SpA., which provided access to data collection for this study. In addition, the authors acknowledge financial support from FONDECYT (1181648) and the Pontificia Universidad Católica de Chile. Rodrigo Herrera acknowledges financial support for Ph.D. studies from VRI of PUC and CONICYT-PCHA/National Doctorate/2018 -21180884

## REFERENCES

Alarcón, D. M., Alarcón, I. M., and Alarcón, L. F. (2013). "Social Network Analysis : a Diagnostic Tool for Information Flow in the Aec Industry." *21st Annual Conference of the International Group for Lean Construction 2013, IGLC 2013*, International Group for Lean Construction, Fortaleza, 947–956.

Alarcón, L. F., Ashley, D. B., Sucre de Hanily, A., Molenaar, K. R., and Ungo, R. (2011). "Risk Planning and Management for the Panama Canal Expansion Program." *Journal of Construction Engineering & Management*, 137(10), 762–771.

American Institute of Architects California Council. (2007). *Integrated Project Delivery : A Guide*. *The American Intitute of Architects*, California.

Austin, R. B., Pishdad-Bozorgi, P., and de la Garza, J. M. (2015). "Identifying and Prioritizing Best Practices to Achieve Flash Track Projects." *Journal of Construction Engineering and Management*, 142(2), 04015077.

Baiden, B. K., Price, A. D. F., and Dainty, A. R. J. (2006). "The extent of team integration within construction projects." *International Journal of Project Management*, 24(1), 13–23.

Cash, P., Dekoninck, E. A., and Ahmed-Kristensen, S. (2017). "Supporting the development of shared understanding in distributed design teams." *Journal of Engineering Design*, Taylor & Francis, 28(3), 147–170.

Castillo, T., Alarcón, L. F., and Pellicer, E. (2018a). "Influence of Organizational Characteristics on Construction Project Performance Using Corporate Social Networks." *Journal of Construction Engineering & Management*, 34(4), 1–9.

Castillo, T., Alarcón, L. F., and Salvatierra, J. L. (2018b). "Effects of Last Planner System Practices on Social Networks and the Performance of Construction projects." *Journal of Construction Engineering and Management*, 144(3), 1–10.

Cisterna, D. A. (2017). "Application of Social Network Analysis in Lean Infraestructure Projects." Universität Stuttgart.

Craft, R. C., and Leake, C. (2002). "The Pareto principle in organizational decision making." *Management Decision*, 40(8), 729–733.

Dainty, A. R. J., Briscoe, G. H., and Millett, S. J. (2001). "Subcontractor perspectives on supply chain alliances." *Construction Management and Economics*, 19(8), 841–848.

Dave, B., Kubler, S., Främling, K., and Koskela, L. (2014). "Addressing information flow in lean production management and control in construction." *22nd Annual Conference of the International Group for Lean Construction, IGLC 2014*, International Group for Lean Construction, Oslo, 581–592.

European Commission. (2003). " Commission recommendation concerning the definition of micro, small and medium-sized enterprises." *Official Journal of the European Union, 361-EC, 1-6.*

Flores, F. (2015). *Conversaciones para la acción y ensayos seleccionados*. (M. Flores, ed.), Createspace Independent Pub, Bogotá.

Flores, J., Ruiz, J. C., Alarcón, D., Alarcón, L. F., Salvatierra, J. L., and Alarcón, I. (2014). "Improving Connectivity and Information Flow in Lean Organizations - Towards an Evidence-Based Methodology." *22nd Annual Conference of the International Group for Lean Construction 2014, IGLC 2014*, International Group for Lean Construction, Oslo, 1109–1120.

Al Hattab, M., and Hamzeh, F. (2015). "Using social network theory and simulation to compare traditional versus BIM-lean practice for design error management." *Automation in Construction*, Elsevier B.V., 52(4), 59–69.

Herrera, R. F., Mourgues, C., and Alarcón, L. F. (2018). "Assessment of Lean Practices, Performance and Social Networks in Chilean Airport Projects." *26th Annual Conference of the International Group for Lean Construction 2018, IGLC 2018*, International Group for Lean Construction, Chennai, 603–613.

Hickethier, G., Tommelein, I. D., and Lostuvali, B. (2013). "Social network analysis of information flow in an IPD-project design organization." *21st Annual Conference of the International Group for Lean Construction 2013, IGLC 2013*, International Group for Lean Construction, Fortaleza, 319–328.

Hoppe, B., and Reinelt, C. (2010). "Social network analysis and the evaluation of leadership networks." *The Leadership Quarterly*, 21(4), 600–619.

Karp, N. C., Hauer, K. E., and Sheu, L. (2019). "Trusted to Learn: a Qualitative Study of Clerkship Students ' Perspectives on Trust in the Clinical Learning Environment." *Journal of General Internal Medicine*, Journal of General Internal Medicine, 34(5), 662–668.

Kereri, J. O., and Harper, C. M. (2019). "Social Networks and Construction Teams: Literature Review." *Journal of Construction Engineering and Management*, 145(4), 03119001.

Kleinsmann, M., Deken, F., and Dong, A. (2012). “Development of design collaboration skills.” *Journal of Engineering Design*, 23(7), 485–506.

Knotten, V., Lædre, O., and Hansen, G. K. (2017). “Building design management–key success factors.” *Architectural Engineering and Design Management*, 13(6), 479–493.

Koo, C. W., Park, S. H., Yi, J. S., and Kwon, O. K. (2013). “Development of web-based design management system through user participatory design and use-case modeling.” *International Journal of Civil Engineering*, 11(1), 23–32.

Long, D., and Arroyo, P. (2018). “Language, moods, and improving project performance.” *26th Annual Conference of the International Group for Lean Construction 2018, IGLC 2018*, International Group for Lean Construction, Chennai, 495–504.

Love, P. E. D., Irani, Z., Cheng, E., and Li, H. (2002). “A model for supporting inter-organizational relations in the supply chain.” *Engineering, Construction and Architectural Management*, 9(1), 2–15.

Marin, A., and Wellman, B. (2011). “Social Network Analysis: an introduction.” *The SAGE Handbook of Social Network Analysis*, J. Scott and P. J. Carrington, eds., 11–25.

Medina-Mora, R., Winograd, T., Flores, R., and Flores, F. (1992). “The action workflow approach to workflow management technology.” *CSCW 92 Proceedings*, 281–288.

Ng, S. T., and Tang, Z. (2010). “Labour-intensive construction sub-contractors: Their critical success factors.” *International Journal of Project Management*, Elsevier Ltd and IPMA, 28(7), 732–740.

Oluwatayo, A. A., and Amole, D. (2013). “Ownership , structure , and performance of architectural firms.” *Frontiers of Architectural Research*, Elsevier, 2(1), 94–106.

Oviedo-Haito, R. J., Jiménez, J., Cardoso, F. F., and Pellicer, E. (2014). “Survival Factors for Subcontractors in Economic Downturns." *Journal of Construction Engineering & Management*, 140(3), 04013056.

Paris, C. R., Salas, E., and Cannon-Bowers, J. A. (2000). "Teamwork in multi-person systems: A review and analysis." *Ergonomics*, 43(8), 1052–1075.

Phelps, A. F. (2012). "Behavioral Factors Influencing Lean Information Flow in Complex Projects." *20th Annual Conference of the International Group for Lean Construction 2012, IGLC 2012*, International Group for Lean Construction, San Diego.

Priven, V., and Sacks, R. (2013). "Social network development in Last Planner System implementations." *21st Annual Conference of the International Group for Lean Construction 2013, IGLC 2013*, International Group for Lean Construction, Fortaleza, 474–485.

Pryke, S. (2012). *Social network analysis in construction*. Wiley-Blackwell.

Rahmawati, Y., Utomo, C., Anwar, N., Negoro, N. P., and Nurcahyo, C. B. (2014). "A framework of knowledge management for successful group decision in design process." *2014 IEEE Conference on Open Systems (ICOS)*, Subang, Malaysia, 60–65.

Richards, W., and Macindoe, O. (2010). "Characteristics of Small Social Networks." *Technical report, Computer Science and Artificial Intelligence Laboratory, MIT*, Cambridge, MA, 40.

Rojas, M. J., Herrera, R. F., Mourgues, C., Ponz-Tienda, J. L., Alarcón, L. F., and Pellicer, E. (2019). "BIM Use Assessment (BUA) Tool for Characterizing the Application Levels of BIM Uses for the Planning and Design of Construction Projects." *Advances in Civil Engineering*, 2019, 1–9.

Savolainen, J. M., Saari, A., Männistö, A., and Kähkonen, K. (2018). "Indicators of collaborative design management in construction projects." *Journal of Engineering,* *Design and Technology*, 16(4), 674–691.

Schöttle, A., Haghsheno, S., and Gehbauer, F. (2014). "Defining Cooperation and Collaboration in the Context of Lean Construction." *In 22nd Annual Conference of the International Group for Lean Construction.*, International Group for Lean Construction, Oslo, 1269–1280.

Schröpfer, V. L. M., Tah, J., and Kurul, E. (2017). "Mapping the knowledge flow in sustainable construction project teams using social network analysis." *Engineering , Construction and Architectural Management*, 24(2), 229–259.

Scott, J. (2017). *Social Network Analysis*. (M. Steele, ed.), SAGE Publications, London.

Searle, J. R. (1969). *Speech acts: An essay in the philosophy of language*. (Cambridge university press., ed.), Berkeley.

Segarra, L., Herrera, R. F., Alarcón, L. F., and Pellicer, E. (2017). "Knowledge management and information flow through social networks analysis in chilean architecture firms." *25th Annual Conference of the International Group for Lean Construction, IGLC 2017*, International Group for Lean Construction, Heraklion, 413–420.

Sonnenwald, D. H. (1996). "Communication roles that support collaboration during the design process." *Design Studies*, 17(3), 277–301.

Svalestuen, F., Frøystad, K., Drevland, F., Ahmad, S., Lohne, J., and Lædre, O. (2015). "Key Elements to an Effective Building Design Team." *International Conference on Project Management*, Elsevier Masson SAS, Sapporo, 838–843.

Sydow, J., and Braun, T. (2018). "Projects as temporary organizations: An agenda for further theorizing the interorganizational dimension." *International Journal of Project Management*, Elsevier Ltd and Association for Project Management and the

International Project Management Association, 36(1), 4–11.

Turner, J. R., and Müller, R. (2003). “On the nature of the project as a temporary organization.” *International Journal of Project Management*, 21(1), 1–8.

Valentine, M., Nembhard, I., and Edmondson, A. (2015). “Measuring Teamwork in Health Care Settings: A Review of Survey Instruments.” *Medical Care*, 53(4), 16–30.

Viana, D. D., Formoso, C. T., and Isatto, E. L. (2011). “Modelling the network of commitments int the Last Planner System.” *Lean Construction Journal*, 7(1), 55–67.

Wesz, J. G. B., Formoso, C. T., and Tzortzopoulos, P. (2018). “Planning and controlling design in engineered-to-order prefabricated building systems.” *Engineering, Construction and Architectural Management*, 25(2), 134–152.

Wong, P. S. P., Demertjis, M., Hardie, M., and Lo, C. yiu. (2014). “The effect of unlearning on organisational learning behaviour and performance in construction contracting organisations.” *International Journal of Project Organisation and Management*, 6(3), 197.

Zhang, L., and Ashuri, B. (2018). “BIM log mining: Discovering social networks.” *Automation in Construction*, 91(3), 31–43.