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Additional Information

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

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5  
6 **Abstract**

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

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

22

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

25

## 26 INTRODUCTION

27 The architecture, engineering and construction industry (AEC) is fragmented into  
28 several specialties that correspond to the different phases of a project (Dainty et al. 2001;  
29 Love et al. 2002). A high degree of fragmentation requires better interaction between the  
30 specialties (Ng and Tang 2010). The interaction of a work team is generated through  
31 communication, coordination and collaboration among the participants (Schöttle et al.  
32 2014). This interaction can be represented as the information flow between the right people  
33 at the right time (Dave et al. 2014; Al Hattab and Hamzeh 2015).

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

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

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

47 More fragmentation requires more interaction, which must be approached by  
48 considering the social and technological factors. These factors together allow the  
49 information flows to be suitable for the desired interaction. A project team with greater  
50 interaction may generate an increase in trust and learning in work teams, achieving high  
51 levels of commitment and understanding between the participants (Phelps 2012). Flores et  
52 al. (2014) claim that by improving the interaction of information flows between people,  
53 improved project performance can be achieved. An interaction in a work team can be  
54 represented as a network of commitments among its members, who establish reliable  
55 commitments among themselves, to achieve the objectives of the project (Viana et al.  
56 2011).

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

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

74 There are studies evaluating the social networks in the AEC at an organizational or  
75 company level (Castillo et al. 2018a; Segarra et al. 2017) or at the level of a construction  
76 project (Castillo et al., 2018b) in which all the participants are from the same workplace.  
77 These studies use standard social network metrics for all the dimensions of interactions  
78 without providing a specific interpretation for each network. In addition, such metrics are  
79 applicable to large organizations, and they are difficult to interpret in small work teams,  
80 such as temporary organizations created during the design phases of construction projects.  
81 A large organization is defined as one that exceeds the limits of medium-sized companies  
82 (250 people) and small companies (49 people) (European Commission 2003); however, it is  
83 difficult to clearly define the size of a network to characterize it. Richards and Macindoe  
84 (2010) propose that a small network is one with fewer than 100 members, while a large  
85 network has more than 1000 nodes. Therefore, design project teams are small social  
86 networks because the number of members is fewer than 50 people. According to a previous  
87 report (Segarra et al. 2017), when a network is small, there is a greater possibility of  
88 sharing important information because the network facilitates interaction among its  
89 members.

90 Previous studies on social networks in the construction industry provide valuable  
91 information mostly about large organizations (e.g., Flores et al. 2014) in construction

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

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

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

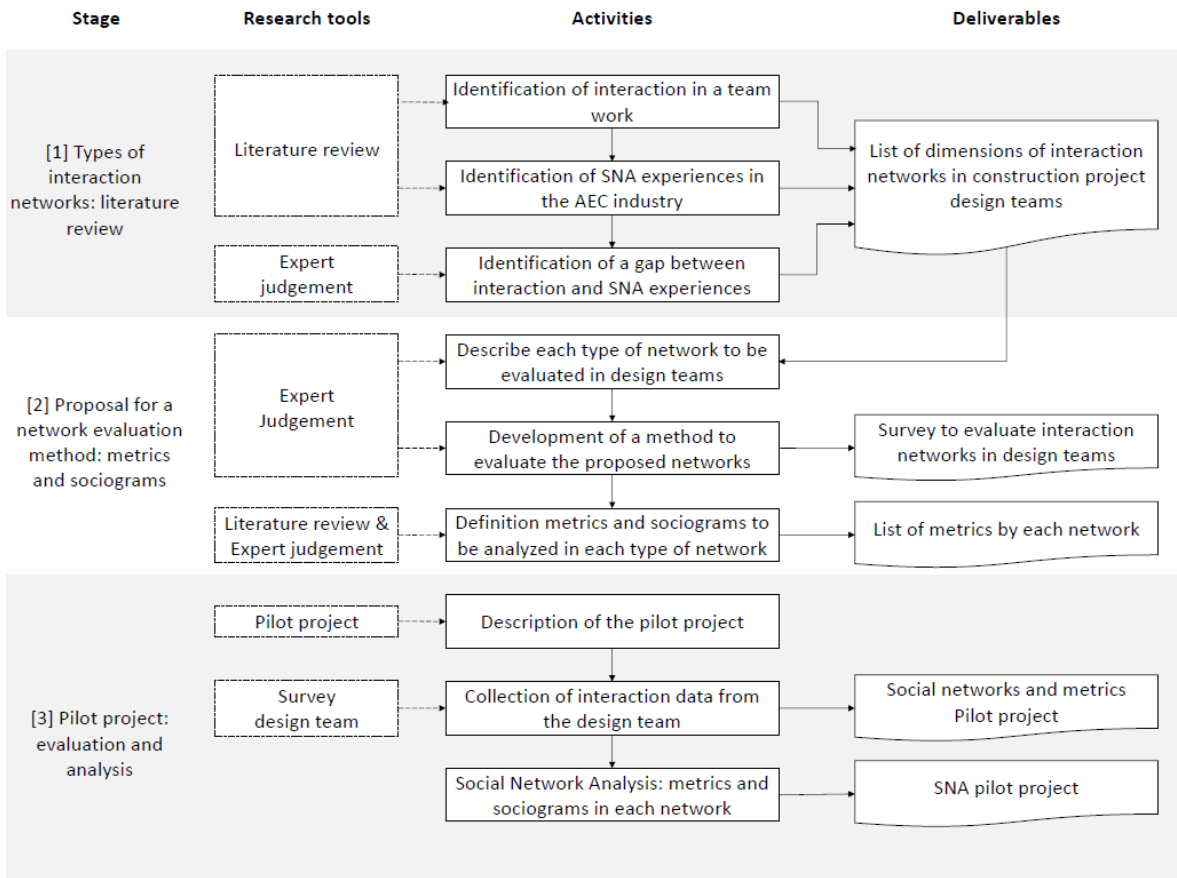
120

## 121 RESEARCH METHODOLOGY

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

128 In the first stage, a literature review of specialized journals in engineering and  
129 construction project management and of the proceedings of major conferences held  
130 between 2008 and 2019 was carried out. The search was carried out in the following online  
131 libraries: Engineering Village, Web of Science and Scopus. The topics sought were  
132 interaction, teamwork, team effectiveness, SNA, team integration and team collaboration;  
133 all the papers selected were from the AEC industry. This first review aimed to identify the  
134 dimensions of teamwork, which can be defined as an interaction between two or more  
135 people in a design team. The literature review identified a perspective of the interaction of  
136 work teams associated with the commitment network generated among them. Therefore, a  
137 list of dimensions of interaction was compiled and grouped into two categories: traditional  
138 interaction and commitment management. In addition, a review of the literature associated  
139 with the use of SNA in the AEC industry was conducted. Some metrics and characteristics

140 of this type of analysis were presented, exemplifying different case studies reported in the  
 141 literature. Finally, the gap between the dimensions of the interactions associated with an  
 142 effective team and the use of SNA in the AEC industry was identified.  
 143



144

145

**Fig. 1.** Research methodology stages

146 In the second stage, the authors proposed a method to assess the interaction in a design  
 147 team of a construction project, using the design team as the unit of analysis. The list of  
 148 interaction dimensions for this type of project was the input to develop this stage, and the  
 149 team developed the interaction network method for the design teams of construction  
 150 projects in four multidisciplinary work sessions that included engineers, architects,



151 builders, consultants and linguists. In the first session, the team described each dimension  
152 of interaction that would be evaluated in this type of project and the type of link framed in  
153 the SNA. In the second and third sessions, the team created the data collection survey and  
154 identified the objective of the instrument, potential survey participants and distribution  
155 method. In the fourth session, based on a review of the literature and its experience, the  
156 team defined the metrics and sociograms that should be analyzed in each of the networks,  
157 as well as the validation criteria. The final deliverable of this stage was the network  
158 evaluation method in construction project design teams, which included a description of the  
159 interaction dimensions, definitions of each interaction link type, the survey participants, the  
160 collection method and the questions for the data collection, data validation, and definitions  
161 of the metrics and sociograms to be analyzed for each interaction dimension.

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

172

## 173 LITERATURE REVIEW OF INTERACTION NETWORKS

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

181

### 182 Dimensions of interaction in a work team

183 For a work team to be effective, several conditions associated with a compelling  
184 direction, an enabling structure, a supportive organizational context and team coaching  
185 must be present; teamwork has multiple dimensions that must be evaluated (Valentine et al.  
186 2015). Specifically, some key performance elements of construction project design teams  
187 are as follows: the encouragement of collaboration, creation of a unique and challenging  
188 project, involvement of the team members in planning, commitment to the team,  
189 acceleration of the team-building process, commitment of the members to the goal, a sense  
190 of purpose, dedication to the time and effort required to form a team, opportunity for the  
191 team members to become familiar with each other and the project, increased collaboration  
192 in the whole project, identification of the design team member roles and trust between the  
193 team members (Svalestuen et al. 2015).

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

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

206

207 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%

208

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

216 Typically, design teams adopt a goal-oriented approach by prioritizing and sharing only  
217 what is necessary; therefore, they exhibit a distributed knowledge system, in which they  
218 rely on each person properly knowing his or her role and on the concept that not everyone  
219 needs to know everything to succeed in a design project (Kleinsmann et al. 2012). The  
220 collaborative approach of team members is accompanied by systematic discussion and  
221 negotiation (Kleinsmann et al. 2012); thus, a shared understanding among all the team

222 members when they are making agreements is essential (Cash et al. 2017). This shared  
223 understanding implies that the interaction of team members must be based on continuous  
224 cycles of commitment (Viana et al. 2011).

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

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

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

253

#### 254 SNA experiences in the AEC industry

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

260

261

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)

262

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

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

280 be searched for in both undirected and directed graphs. However, there are important  
281 differences between the two situations (Marin and Wellman 2011).

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

291 The relevant characteristics to carry out an SNA are the following: type of organization,  
292 dimension of interaction and metrics. Table 3 exemplifies each of these characteristics from  
293 prior research that used SNA in AEC organizations. All these studies present case studies in  
294 which an SNA was carried out, with the exception of the work of Al Hattab and Hamzeh  
295 (2015), who present a theoretical analysis of an organization. In all the case studies  
296 presented in Table 3, data capture is carried out through surveys (paper or online)  
297 conducted on the participants of the analysis (Flores et al. 2014; Herrera et al. 2018);  
298 therefore, it must be assumed that there may be some subjectivity in the input data of the  
299 SNA.

300



Table 3: SNA experiences in the AEC industry

<b>Source</b>	<b>Type of organization</b>	<b>Types of interactions</b>	<b>Metrics</b>
(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

302

303 From the examples presented in the AEC industry (Table 3), the networks most  
304 frequently measured are those of interaction and information flow, and the metrics most  
305 analyzed are those linked to the organization (density, diameter, average path length) and  
306 not to the people (degree, centrality, betweenness). In addition, the analyses are performed  
307 on companies (Alarcón et al. 2013; Flores et al. 2014; Segarra et al. 2017) or complex  
308 projects (Hickethier et al. 2013; Priven and Sacks 2013; Schröpfer et al. 2017), where the

309 number of participants is high (50 people or more). Furthermore, in these studies, it is not  
310 specified whether the links of the networks are directed or undirected, with the exception of  
311 Al Hattab and Hamzeh (2015), who clarify that the interaction has undirected links. In  
312 addition, none of these studies include a study carried out on the number of connected  
313 components.

314

### 315 Gaps in SNA in the AEC industry

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

329 For each dimension of interaction, an analysis of the social network can be performed;  
330 therefore, for each interaction, the links must be defined as directed or undirected,  
331 according to the nature of the interaction (Hoppe and Reinelt 2010). According to the SNA  
332 experiences in the AEC industry, this definition is not explicit; however, it is fundamental

333 to the analysis of metrics and input data filtering because some metric calculations are  
334 affected depending on the characteristics of the link (Scott 2017).

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

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

350

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

### 352 SOCIOGRAMS

353 The objective of this evaluation method is to capture data from different dimensions of  
354 interaction in construction project design teams. To develop the method, the following steps  
355 were followed: (1) definition of the interaction dimensions and description and definition of  
356 the link type for each interaction, (2) definition of the participants involved in the data

357 capture and the data capture method, (3) definition of the questions (and type of answer) to  
 358 capture information for each interaction, (4) definition and analysis of the metrics and  
 359 sociograms for each dimension of interaction and validation data criteria and (5) data  
 360 collection and analysis.

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

368

369 Table 4: Descriptions of types of interactions – traditional

<b>Type of interaction</b>	<b>Description</b>	<b>Type of link</b>	<b>Source</b>
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)

370

371

Table 5: Descriptions of types of interactions – commitment management

<b>Type of interaction</b>	<b>Description</b>	<b>Type of link</b>	<b>Source</b>
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)

372

373

The people involved in the analysis are all those involved in the design phase, which

374

may vary depending on the nature of the project. The roles that may be stakeholders are the

375

project manager, architect, structural engineer, client, client representative, geotechnical

376

engineer, MEP engineer, BIM manager, planning engineer, general contractor and others

377

(Al Hattab and Hamzeh 2015). The interaction data capture tool is a survey that must be

378 answered by those involved in the design phase. Because these stakeholders typically do  
 379 not work in the same place, it is easier to use an online survey server. It is recommended to  
 380 have a meeting with the project manager to discuss the scope and benefits of the analysis  
 381 and to list the participants and their roles before sending the survey to all the participants.

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

392

393 Table 6. Types of response for each type of interaction

<b>Type of interaction</b>	<b>Response</b>
Knowledge of roles and responsibilities Global Interaction Trust Learning	Yes/No
Relevant work information Collaboration 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 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 Declaration of satisfaction	of the time)
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394

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

414 If the validation of input data has a positive result, then the networks are represented  
415 through an adjacency matrix. This matrix represents the link between pairs of people

416 through a weight; the weight depends on the type of response. Ones and zeros correspond  
417 to responses of yes and no, respectively, and for answers of frequency, “never” is scored  
418 with a zero, and the different levels are classified either in an ascending scale (1, 2, 3) or  
419 with the value of 1 for all responses other than “never”. In directed networks, it does not  
420 matter whether the links are unidirectional or bidirectional, but in undirected networks,  
421 there must be a unique link between person A and person B. Therefore, it is necessary to  
422 make a prior filter eliminating all the invalid interactions. Then, the adjacency matrix must  
423 be loaded on to software that allows SNA, which provides metrics and sociograms for each  
424 dimension of interaction.

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

435 To apply the proposed method, the activities outlined in Fig. 2 should be carried out.  
436 For the creation of the survey, it is first necessary to establish the initial conditions, such as  
437 (1) the definition of the interaction time period (e.g., the 12 weeks used in this pilot  
438 project); (2) definition of the data collection method, which, for noncollocated teams, is  
439 usually an online survey server or an in-person survey; (3) definition of the study



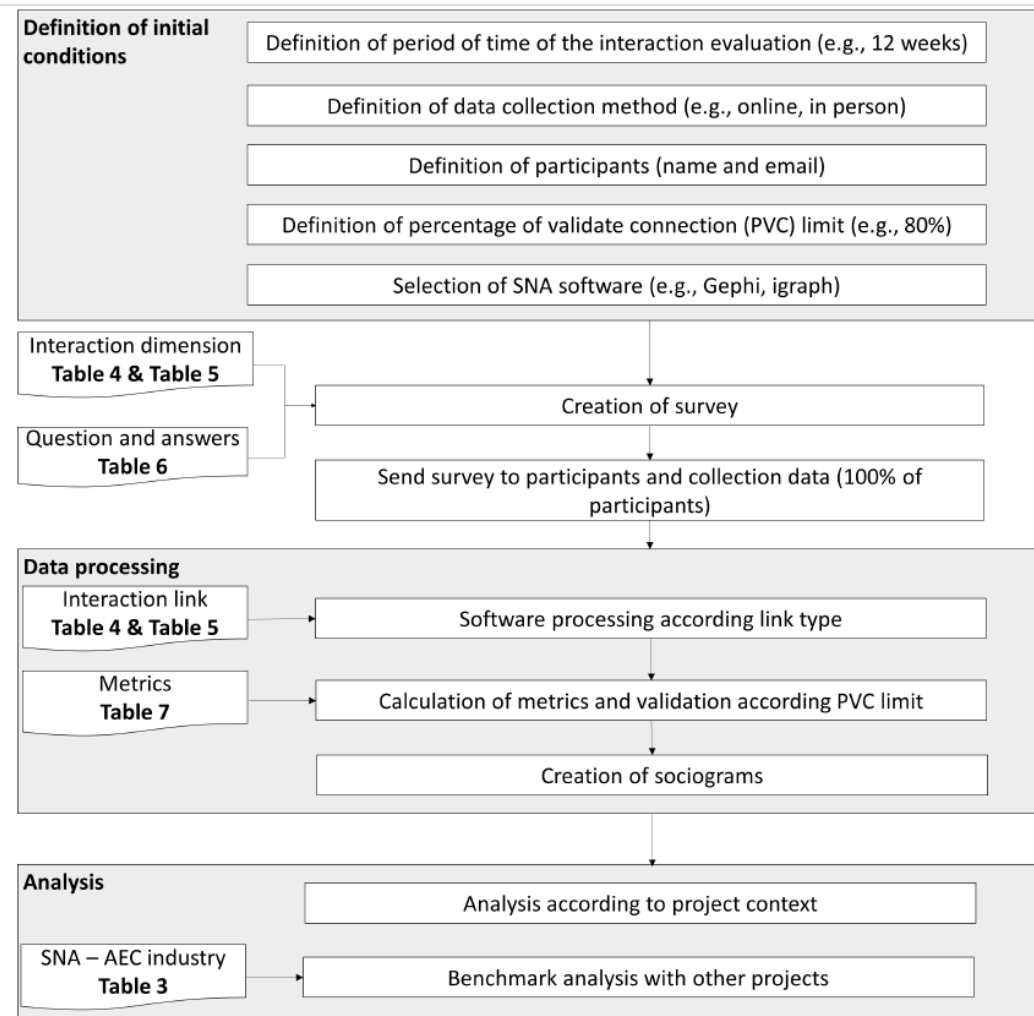
440 participants (client, architect, specialist engineers, project manager, etc.); (4) definition of  
 441 the limit for the PVC for validation of the reliability of the answers obtained; and (5)  
 442 selection of the software to carry out the SNA (there are several free software packages  
 443 such as Gephi and iGraph). Second, the survey should be created considering all the  
 444 previous information, the descriptions of the interaction dimensions (Tables 4 and 5) and  
 445 the questions and answers for the evaluation (Table 6). Third, the survey should be sent to  
 446 the defined participants and the data collected; for small teams, it is recommended that  
 447 100% of the defined participants respond. Then, with the information collected, the data are  
 448 processed using the selected software, according to the type of link of each interaction  
 449 dimension, directed or undirected (information available in Tables 4 and 5). Then, the  
 450 metrics are calculated according to the definitions in Table 7, and the PVC limit criterion is  
 451 reviewed to determine whether the analysis can continue. If the PVC criterion is satisfied,  
 452 then the sociograms are created and the analysis proceeds. Finally, the analysis consists of  
 453 two parts: an analysis of the metrics and sociograms according to the project context, which  
 454 can be done between the assessor and project manager, and a comparative analysis with  
 455 other experiences in the AEC industry reported in the literature (Table 3).

456 Table 7. Proposed metric for each network

<b>Type of network</b>	<b>Metrics</b>
Knowledge of roles and responsibilities	In-degree of each node; Mean in-degree of the network
Global interaction	Degree of each node; Mean and range degree of the network; Network density; # connected components
Relevant work information	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
Learning	
Collaboration	Percentage of bidirectional links; Degree of each node; Mean and range degree of the network; Network density; # connected components
Planning and problem solving	
Trust	# links trust network / # links knowledge of roles network

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

457



458

459

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

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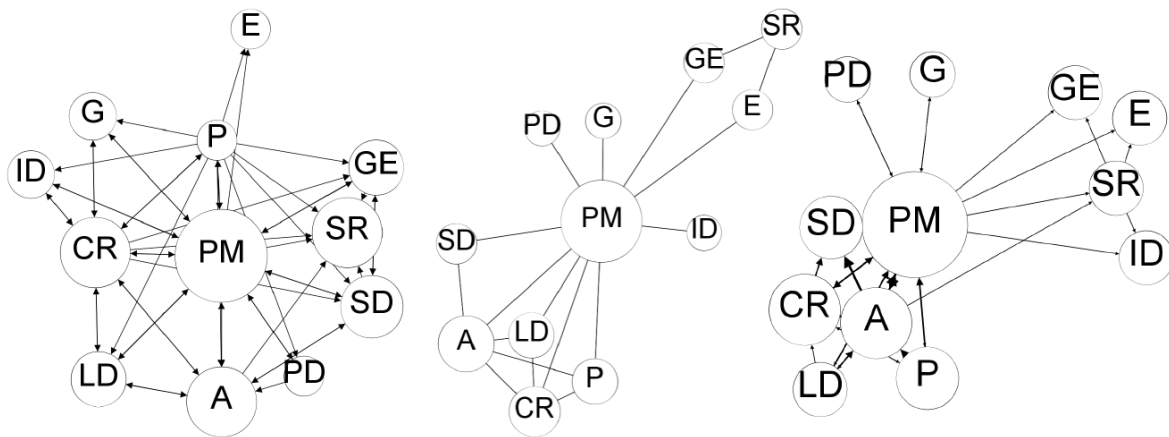
461 **PILOT PROJECT: EVALUATION AND ANALYSIS**

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

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

482 Currently, there are no studies that define the ideal range for the metrics; however, a  
483 comparative analysis was performed using the values obtained from projects of similar size  
484 (number of participants). Because a project is a temporary organization in which all the

485 participants have the common objective of carrying out the design, it is expected that all the  
 486 participants know their roles, and the mean degree must be close to the number of  
 487 participants minus one. In the pilot project, the average grade was 4.33, i.e., one person  
 488 knew the role of approximately four other people. Fig. 3 (left) shows the role knowledge  
 489 network, in which the size of the nodes is proportional to the level of knowledge of the  
 490 entire organization toward that node (indegree). Therefore, in this organization, the  
 491 knowledge toward the project manager was at the first level, with the area of architecture  
 492 and structures at the second level and other design specialties at the third level. In a small  
 493 team such as the one in this project, one would expect all the specialists to know the roles  
 494 and responsibilities of the others (Svalestuen et al. 2015). However, on average in this  
 495 project, each person knew the role of only one-third of the team.



496  
 497 **Fig. 3.** Knowledge of roles network (left)/ Global interaction network (middle)/ Relevant work  
 498 information (right)

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

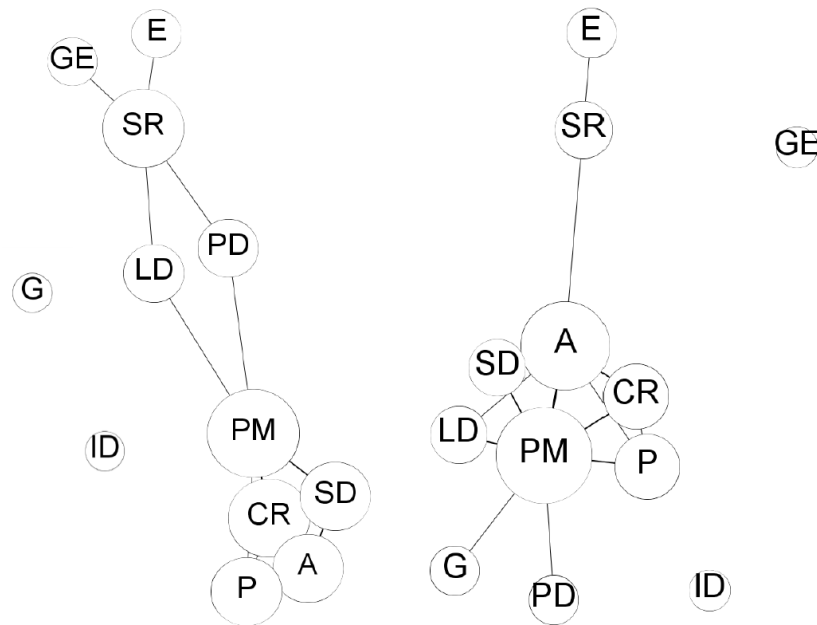
503 1, and the highest degree was 10. This density value was low compared to the value  
504 obtained in the airport design teams in which the density of the interaction network was  
505 approximately 0.5 (Herrera et al. 2018). This phenomenon may have been due to the  
506 context of the typology of the project, e.g., in architecture offices the density varies  
507 between 0.4 and 0.5 in teams of this size (Segarra et al. 2017), or in construction teams on  
508 the worksite, the density varies between 0.4 and 0.7 (Priven and Sacks 2013). The project  
509 manager is the node with the highest number of connections, and from this node there is a  
510 connected group (number of connected components equal to 1). In this work, the project  
511 manager was an important node of articulation, because if it was taken out of the network,  
512 then the number of connected components increased to five, leading to a team with two or  
513 more subgroups (in this case five), in which the interaction between the specialists and  
514 other team members might be difficult. Note that in this case, the global interaction network  
515 is a subnetwork of the role knowledge network, i.e., for people who can interact, first the  
516 roles of each of the team participants must be presented and defined. Therefore, the kick-off  
517 meetings are essential to initiate the expected interaction between the different  
518 professionals (Koo et al. 2013), and they should be utilized in all project teams.

519 Fig. 3 (right) shows the relevant work information network in the pilot project, and the  
520 thickness of the arrow represents the frequency of the information flow, i.e., the network. A  
521 thicker arrow shows a higher frequency of information. The reciprocal connections, which  
522 constituted 67.65% of the information network, included the participation of the client's  
523 representative, the project manager, the architect, the structural designer and a few  
524 specialist designers. The density was 0.258, which was low compared to the value obtained  
525 in airport design teams in which the density of the interaction network was approximately  
526 0.4 (Herrera et al. 2018). Moreover, in larger design teams (between 40 and 60 people) the

527 integrated density was approximately 0.1 (Al Hattab and Hamzeh 2015). Thus, a team four  
528 or five times larger than the pilot project only reduced the density by half. The mean  
529 indegree was 2.83, and its range was 7; the mean outdegree was 2.830, and its range was  
530 10. Therefore, there was high variability regarding the sharing of work information, which  
531 demonstrated an inhomogeneous flow of information that focused on the project manager  
532 and the architect. There was one weakly connected component and five strongly connected  
533 components. Thus, the network was weakly connected, and, as in the interaction network, it  
534 was strongly dependent on the project manager, which was contrary to the goals of lean  
535 management practices regarding the transparency of information (Wesz et al. 2018) and  
536 was greater among the specialists through technology (American Institute of Architects  
537 California Council 2007).

538 Collaboration and planning are strongly related to problem-solving networks because  
539 planning can be a type of collaboration. Therefore, the planning network should be a subnet  
540 of the collaboration network. Both types of networks have undirected links, and all invalid  
541 connections must first be removed. In the case study, both networks had similar  
542 characteristics, which was evidenced by their indicators. The proportion of reciprocal  
543 connections was 90.32% in both cases, which explained the high reliability of the input  
544 data. Additionally, in both networks, there were two disconnected people (three related  
545 components), meaning there was no collaborative planning. Finally, the collaboration and  
546 planning had a density of 0.212 and a mean degree of 2.330. Thus, there were 10 people  
547 who were connected; however, for most of the opportunities the project manager was the  
548 intermediary (Fig. 4). Therefore, in this project, there were no planning activities and  
549 collaborative work because the planning was carried out in meetings of two or three people  
550 and not among the 12 people who made up the work team. Current technologies and design

551 methodologies support collaborative work and planning among the specialists to achieve  
552 greater understanding and time efficiency in projects, which produces better results in the  
553 designed product (Rahmawati et al. 2014).

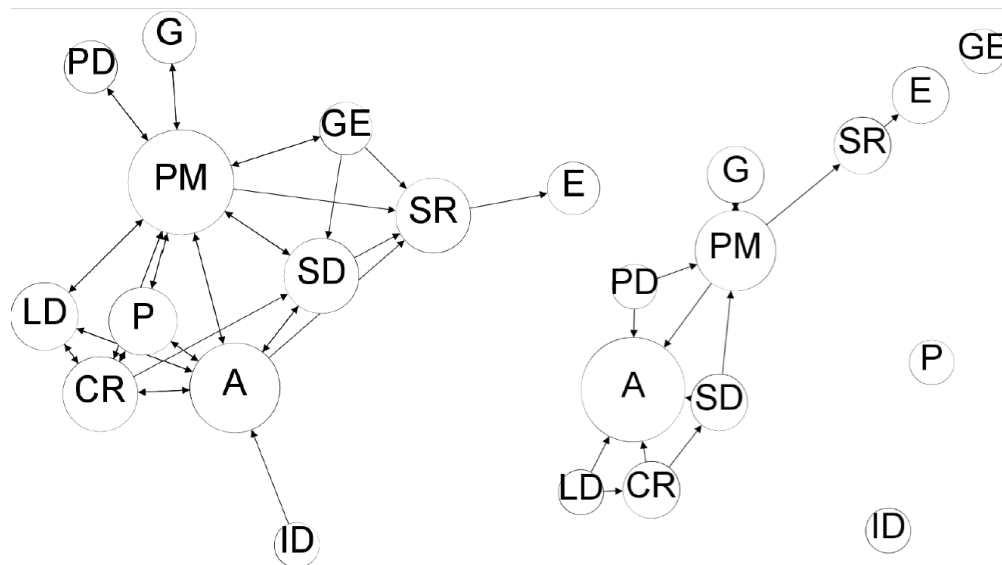


554

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

556 The level of trust between members of a team is fundamental for a team to be effective  
557 (Austin et al. 2015). In the pilot project, the trust network was created (Fig. 5). In this  
558 project, there were 36 connections of trust and 52 connections of knowledge of roles, which  
559 meant that the relative level of trust was 0.690 in the network and that there was a high  
560 degree of trust between the people who knew each other. However, note that the level of  
561 knowledge of roles in this organization was low (density 0.394); of the four people a team  
562 member knew, he or she trusted two or three, on average. Therefore, in this team, there was  
563 no problem of trust but rather of knowledge of the team and greater collaboration.  
564 However, there was no evidence that an increase in the links of knowledge would result in  
565 an increase in the network of trust, but it is known that through collaboration and

566 collaborative planning, trust can be strengthened (Flores et al. 2014). To learn from another  
 567 person, it is necessary to trust that person (Karp et al. 2019); therefore, the learning network  
 568 is a subnet of the trusted network (Herrera et al. 2018). In the case study, a small learning  
 569 network was obtained, in which only 9 of the 12 stakeholders of the project participated and  
 570 in which their level of connectivity was weak because their mean degree was 1.083, their  
 571 density was 0.247 and the percentage of reciprocal connections was 7.69%. Thus, an  
 572 average person learned from only one person, although there was an opportunity to learn  
 573 from 11 others. Therefore, in this project, there was an important growth gap in the learning  
 574 network, given that organizations need to be constantly learning, especially with the  
 575 implementation of new technologies (Wong et al. 2014).



576

577

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

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579

580

581

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



582 involved for some task or document. The indegree of person A represents the number of  
583 people who request something from person A and not the number of requirements that  
584 person A has, and the outdegree of person A represents the number of people to whom  
585 person A is sending a request. In the pilot project, the sum of the input degrees of each node  
586 was 27, which meant that there were 27 connections between people, of which 7 were  
587 unidirectional and 20 were bidirectional. In the negotiation requirements network, the  
588 connections can be visualized as a negotiation between those involved. With this  
589 information, the percentage of negotiated requirements in the pilot project was calculated to  
590 be 51.85%.

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

600

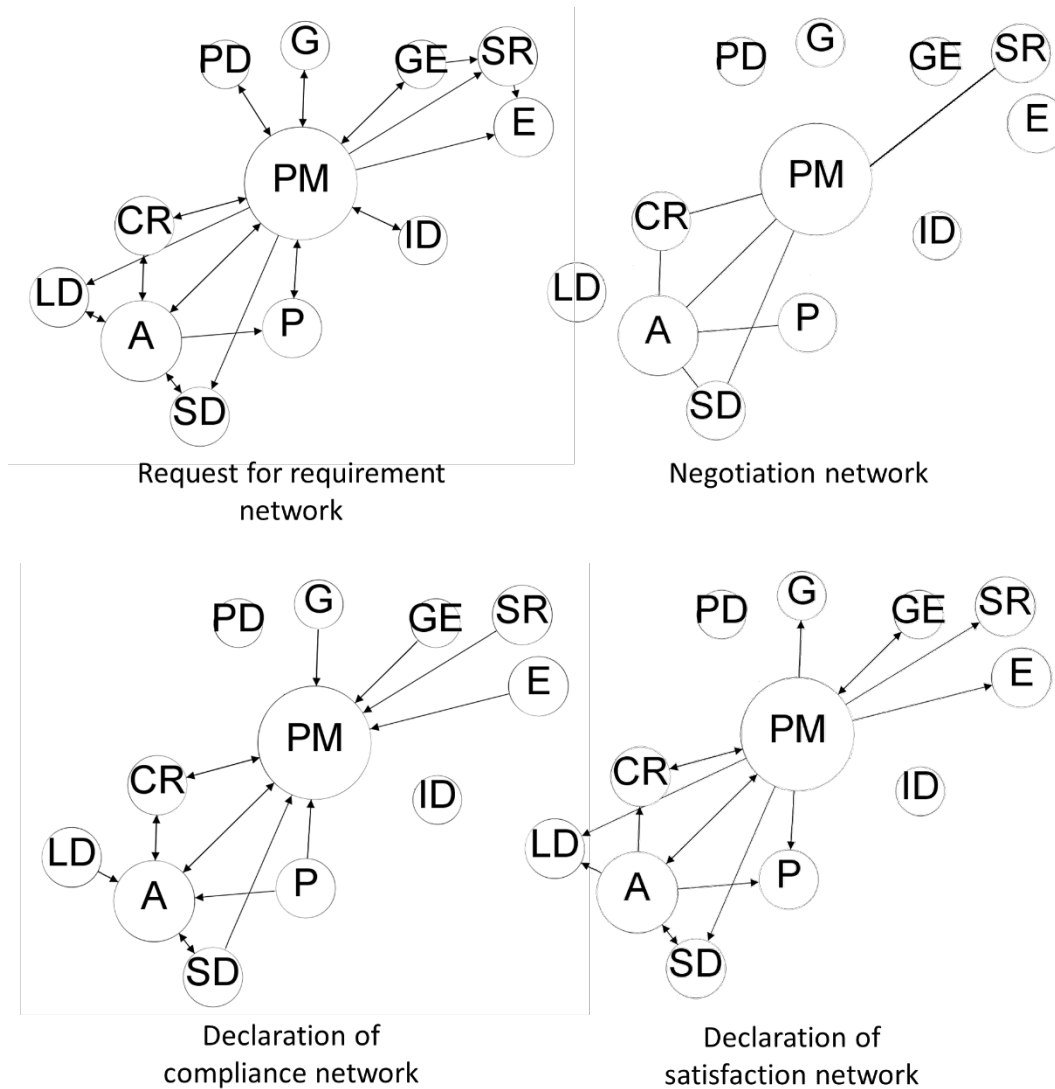


Fig. 6. Commitment management networks

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602

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604 To summarize, in the pilot project, weak interactions were identified that were strongly  
 605 centered on the project manager, with low interactions between different designers. This  
 606 low interaction was initially caused by a lack of knowledge of the roles of the members of  
 607 the team, a critical element in the project, in which each designer was from a different  
 608 company. Thus, the kick-off meeting was fundamental in this project (Koo et al. 2013).  
 609 Regarding commitment management, a low level of negotiation of requirements (clarifying

610 deadlines, resources, scope, etc.) was identified, which affected the declarations of  
611 compliance and satisfaction without achieving the cycle for correct commitment  
612 management. Therefore, there was no continuous cycle of commitments affecting the  
613 shared understanding among the team members (Viana et al. 2011), which may have  
614 affected the design process, generating more rework or other wastes (Cash et al. 2017).

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

634 metrics can be added to analyze and understand the interactions of design teams in  
635 construction projects. In addition, assessments could be done in conjunction with other  
636 techniques for evaluating interaction and teamwork.

637

## 638 CONCLUSIONS

639 For a design team to be successful, the design participants must have high levels of  
640 interaction. To evaluate the interaction, a method was proposed to understand the  
641 interactions in this type of work team using SNA as a tool and evaluating the interaction  
642 from a multidimensional point of view. The key dimensions of interaction in a design team  
643 were identified and grouped into two groups: traditional interaction and commitment  
644 management. The latter group is fundamental in design teams because there are instances of  
645 systematic discussion and negotiation that oblige the team to have a shared understanding  
646 of the actions to be followed. In addition, this was the first time that speech acts were  
647 modeled using SNA. The SNA is a tool that allows global and individual analysis in a  
648 visual format and with mathematical indicators. Each dimension of interaction is  
649 represented as a network and may have an individual analysis; however, it is also necessary  
650 to perform an analysis between two or more networks. The proposed method has the  
651 following practical applications: (a) understanding the interactions of the design team from  
652 several perspectives; (b) taking corrective actions to improve the interaction to make it  
653 more efficient and less dependent on a single person; (c) recognizing the causes that  
654 generate a shared misunderstanding among the members of the team; and (d) taking actions  
655 in this matter, such as generating knowledge of roles, meetings for collective planning, and  
656 opportunities for collaborative work. These benefits can improve the common  
657 understanding of project requirements, reduce waste and increase the value of the design

658 process. The application of the method requires that all the members of the design team  
659 respond to the survey; therefore, there must be a commitment from the organization that is  
660 being assessed. In addition, respondents should equally understand the questions, so the  
661 evaluation team should write the questions in context and verify the PVC limit through  
662 coherence analysis. In addition, the evaluation team and the design team should understand  
663 this method as a tool for continuous improvement and not as a punitive mechanism.

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

676

## 677 DATA AVAILABILITY STATEMENT

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

681

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