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APPLICATION OF SOCIAL NETWORK ANALYSIS IN LEAN AND INFRASTRUCTURE PROJECTS

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ABSTRACT

The communication structures between project participants have a great influence on the success of a project. Some can be described explicitly but most are informal and tacit. Social Network Analysis (SNA) is a tool to identify and model actual social structures with a set of metrics. This paper examines the application of SNA in German, Swiss and Chilean construction projects in order to identify the suitability of SNA in the Architecture, Engineering and Construction (AEC) industry. The scope of the present work focuses on differences when applying SNA to projects and organizations, influence of project complexity, cultural aspects and the use of SNA-metrics for a project benchmarking.

KEYWORDS

Social network analysis (SNA), information flow, collaborative work, organizational design

INTRODUCTION

During the last years, Lean construction principles and practices have proven to be a good alternative to decrease the variability and uncertainty in project planning and execution. Although the introduction of Lean construction has positively impacted project management, there remains further scope for improvement. "Lean thinking" aims to

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introduce improvements mainly at process-level, creating solid structures and smart systems to increase productivity. Such improvements work well in the manufacturing industry, where processes run within a stable framework, producing defined and repetitive products. By contrast, the framework of processes in the construction industry is unstable; it deals with the fabrication of unique products at different places, relying much more on dynamic communication and social interaction. Thus, focusing only on process optimization may not have the desired impacts.

Lately, the study of human relations and the resultant information flows within a project or organization have demonstrated to have a great relevance on project performance. Hence, the application of Social Network Analysis (SNA) within the ambit of Architecture, Engineering and Construction (AEC) offers great potential, since it can be used a) to discover the importance of informal social structures that coexists with formal ones, b) to move towards a more flexible organizational team model which is work-oriented and more dependent on knowledge assets (information flow), and c) to quickly develop close cooperation relationships(Cross et al. 2002).

The application of SNA in the AEC industries is still a novel approach under development. Several attempts have been carried out during recent years to give interpretations to its results and to find correlations between Key Performance Indicators (KPIs) and different SNA-metrics. Nevertheless, most of these studies had to be done almost from scratch. This implies that none of these were undertaken based upon the already assimilated knowledge and/or through analysis of various Lean approaches utilized by projects executed in different countries.

The aim of this work is a comprehensive investigation about how SNA can be applied in the setup of Lean construction projects in the German and Swiss construction market. Furthermore, a comparison with a Chilean infrastructure project is undertaken in order to assess the influence of cultural aspects.

BACKGROUND

COMMUNICATION-STRUCTURESAND LOWPRODUCTIVITY IN CONSTRUCTION

Over the past two decades global productivity in construction remained meager, in comparison with other industries. Many root-causes of this problem are related to communication issues: a) informality and corruption distort the market, b) construction is opaque and highly fragmented, c) design processes and investment are inadequate, and d) poor project management and inefficient on-site execution (Barbosa et al. 2017).

Management practices and human related issues are determining internal factors which influence project performance(Chan et al. 2004). Also, the relationships between the collaborators of an organization have been linked directly with their ability to fulfil objectives (Anklam 2003).In Germany, these type of factors have also been identified as the main causes of deficiencies in construction (Jungwirth 1991).

When it comes to infrastructure projects, in addition to the factors mentioned above, other factors related with communication play a greater role: a) communication with communities neighboring the project: lack of confidence, misinformation and confusion about roles, rumors, community conflicts, expectation management (Mazzei and Scuppa

2006), b) engagement with stakeholders: specially involving the private sector in "reality checking" the results of planning, in particular relating to the financing of projects (Glaister et al. 2010), and c) poor execution: incomplete design, lack of clear scope, ill-advised shortcuts, etc. These projects are so complex that even routine issues can become a major problem (Garemo et al. 2015).

It seems that the analysis of human relations and their consequent information flows within projects or organizations can make a significant contribution towards more productive project execution. Thus SNA is attracting increasing attention in order to enhance trust and collaboration (Chinowsky et al. 2008).

LITERATURE REVIEW: SNA IN THE INTERNATIONAL AEC INDUSTRY

Over the last 5 years, several studies have been carried out on SNA in Chile. Flores et al. (2014) proposed the analysis of 9 networks: interaction, frequent interaction, relevant information, problem solving, successful planning, innovative ideas, leadership, trust and professional feedback. Data was collected through web-based surveys and the analyzed metrics were network density, network diameter, average path length and average degree (Alarcón et al. 2013; Segarra et al. 2017), as well as the difference in network shape. Recent studies have found interesting relationships between project's Last Planner System® (LPS) KPIs and SNA-metrics(Castillo et al. 2015, 2016, 2018).

In the work made by Schröpfer et al. (2017) SNA is applied in three case studies in Germany and in two cases in UK. The research focuses on the analysis of knowledge transfer among project members, relating it to trust networks within the organizations. The findings of the study showed that "large amounts of tacit knowledge were transferred through strong ties in sparse networks […] strong ties do not necessarily equate to a dense network, but can exist in a very sparse network as well." (Schröpfer et al. 2017)

In the USA, SNA has also been implemented, analyzing the importance of early communication in construction projects (Malisiovas and Song 2014). Instead of using a questionnaire survey, they used indirect sources of information: meetings, conversations, e-mails, phone calls, videoconferences, etc. They found that "higher density reveals a higher level of communication, large modularity may imply the creation of isolated groups, as the network becomes more complex its length gradually increases, increasing of the average shortest path reveals a possible threat of future isolated populations to appear, thus leading to poor utilization of individual knowledge and experience."

SNA has also been used to detect unethical behavior in the construction industry and the relationship between corruption and Integrated Project Delivery (IPD). Project participants having high number of connections and centrality have more to lose from unethical conduct than those who are isolated in the network; as they are under an increased surveillance due to their multiple connections, which determine the extent to which news of unethical behavior are disseminated to other project participants. In the study, three communicational structures were identified: a) structural hole, b) mixed and c) simmelian triad. From the analysis of the different structures, the authors concluded that "implementation of Lean IPD in construction may be an effective grass roots weapon for combating corruption" (Thameem et al. 2017).In another study related, Hickethier et al. (2013)have applied SNA to investigate the impact of IPD practices in projects. The researchers concluded that SNA can be used to support the implementation of this collaborative approach. IPD promotes the participation of a greater number of people in the project design, thus increasing the need for coordination. Thereby, SNA can assist the coordination of this larger design team. In Israel, SNA has been implemented in a LPS-Project to explore three aspects: communication, reliability, trust (Priven and Sacks 2013). In China, Li et al. (2011) used SNA with an indirect method of data collection at the 2010 Shangai EXPO, analyzing the relationships of 49 organizational units, 5 major projects and 8 government departments. They considered consortium relations, strategy alliance relations, team relations, contractor and subcontractor relations, working staff relations and other informal relations as connections between them. They concluded that SNA provides a new research perspective, e.g. of construction organizations.

METHODOLOGY

In light of this background, the research aims to answer the following questions:

- How important are cultural aspects when implementing SNA?
- Is SNA equitably suitable for the analysis of projects and organizations?
- How does project complexity influence the applicability of SNA?
- Is it possible to use SNA-metrics for statistical benchmarking of projects?

In order to answer these questions, proven concepts of past SNA implementations were taken to build a first conceptual framework of a SNA-Instrument. Then, the instrument was tested and refined in iterative loops each time in a more complex project scenario: firstly, in a simple organization (consulting office), secondly in two construction projects, thirdly in a complex organization (6 subsidiary consulting offices) and c) in an infrastructure project. The iterations were done in Germany, Switzerland and Chile. The resulting structure of the SNA instrument is illustrated in the Figure.

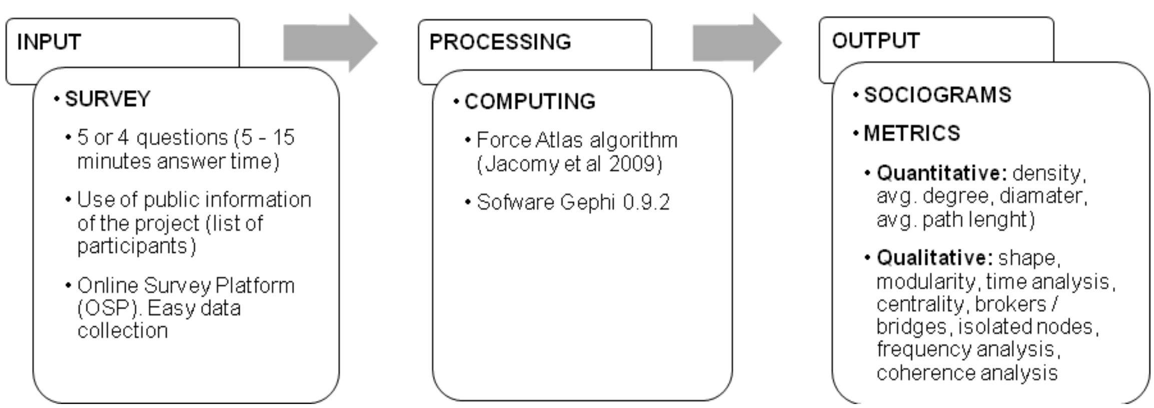


Figure 1: SNA Instrument Structure

The five survey questions concern five different social networks. Table 1contains a brief description of the networks, questions and motivation.

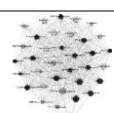
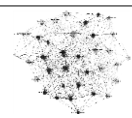
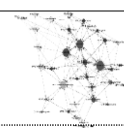
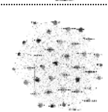
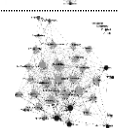
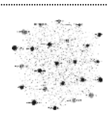
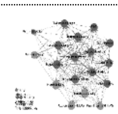
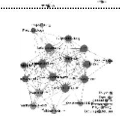
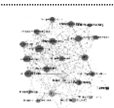
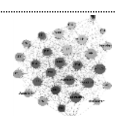
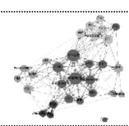
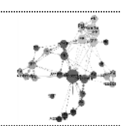
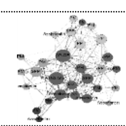
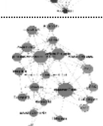
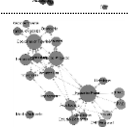
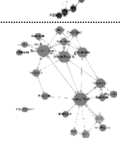
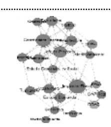
Table 1: Networks analyzed in the SNA Instrument

No	Social Networks	Exploratory question regarding the network	Motivation
1	(RIN) Role identification network	Do you know the role of this person in the project/organization?	Avoid delays finding information, solve problems
2	(WIN) Work Interaction network	Have you interacted with this person in the project/organization during the last 3 months?	Basic network to analyze. Collaborative work
3	(PPRN) Planning & problem resolution network	Select the people with whom you plan and solve problems effectively with. Consider only the past 3 months	Inclusion of stakeholders
4	(KN) Knowledge network	Select all those involved in the project from which you have learned something new that means a contribution in the project you are working on. Consider only the past 3 months	Improve knowledge transfer
5	(TN) Trust network	Select all those involved in the project/organization that you trust in the quality of their work. Consider only the past 3 months	Measure trust in work relationships, in terms of quality and time requirements

RESULTS AND DISCUSSION

Table 2 summarizes the different scenarios used for the iterative design of the SNA-Instrument. Furthermore, it depicts the identified socio grams, in which it can be seen how the different groups (marked with colors) are distributed and with what degree of density they are clustered.

Table 2: List of measured contexts

Project / Organization	RIN	WIN	PPRN	KN	TN
Organization 1 Consulting Office **Germany**					
Project Office Building Construction **Switzerland**					
Project Research center Construction **Switzerland**					
Organization 6 Consulting Offices **Germany**					
Project Airport Expansion Design **Chile**					

The social networks of the observed organizations and lean projects in Germany and Switzerland in general obtained better metrics values than the infrastructure project in Chile. This was demonstrated by higher densities; lower network diameters and average path lengths, more central participants; and better distribution of nodes and network shape. Thus, resulting in better communication and knowledge transfer. The low communication level of the infrastructure project is attributed to the more diverse work teams that constituted the project which were situated in different geographical locations and did not devote 100% of their time to the project, but also to other activities (e.g.: government entities).

The question regarding the Trust Network (TN) was considered too compromising and personal in Germany and Switzerland and could not be applied in these countries. In Chile, the question was allowed.

CULTURAL ASPECTS

In countries such as Germany or Switzerland, where data protection is an important issue, people are more reluctant to respond to surveys without knowing exactly why and howthis information will be used. Obtaining information can be hindered in these countries because implementing SNA involves obtaining data directly from people. Attempts were made to obtain data about the social structure indirectly, through observations, nevertheless these alternatives were rejected because they did not provide high quality data to ensure correct visualization of the networks.

In these contexts, an in-depth explanation of SNA to the respondents, a careful preparation of the questions and a correct survey privacy statement are essential to achieve full survey participation.

PROJECTS AND ORGANIZATIONS

After the application of the SNA-Instrument in different contexts, it was found to be effective for both project and organizational analysis.

Furthermore, the SNA-Instrument can be used more than one time, to compare and register the evolution of the social network along the time. In organizations it can be applied regularly at pre-set time intervals. In projects, multiple SNA implementations might be difficult to carry out, so it is recommended to apply SNA at least at the beginning and at the end of the project. At the beginning it can be used as a good starting point to assess the quality of the communication in project. For example, if the density of the network is high, it may be known in advance that the introduction of new ideas will be more challenging, because in network which are closely connected, when the new information, and, or even, especially new innovation comes in, they might be reluctant to any change (Gasevic 2014). A SNA measurement at the end of the project, will help to demonstrate the effectiveness of the actions taken to improve communication.

PROJECT COMPLEXITY

The full potential of the instrument in identifying conflicting communicational configurations was witnessed in the most complex scenario (infrastructure project).

The SNA-metricsin this project point at weaker communication networks than in normal projects, due to fragmented contracts. Such a fragmented project structure with work assigned to several different bodies, hamper the coordination and collaboration of stakeholders. The communicative structure is quite hierarchical, and therefore riskier, as it generates brokers (bottlenecks) that dangerously gain a lot of influence and power in the management of information within the project. The most significant flow of information goes through these hubs-members, which can filter the information according to their own criteria. Many decisions are made only by these members, so the risk of a bad – or even unethical(Thameem et al. 2017) – decision is concentrated in a few people. Furthermore, if these hubs-members resign or are absent from the project, it would immediately generate delays.

BENCHMARKING

The interpretation of the SNA-Instrument outputs was composed for two points of view: a quantitative analysis and a qualitative analysis (see Table 3).“The human eye is trained in pattern recognition” (Nooy et al. 2005), because of that it is important to make an analysis of the geometric shape of the networks, which will also provide important information. Metrics such as Diameter, Density, (In-Out-Average) Degree, Modularity and Centrality are calculated by algorithms. All of them are represented by numbers which can be categorized to identify the optimal intervals of these values.

Table 3: Type of Analysis for the SNA Instrument Outputs

Analysis	Based on	Instrument
Qualitative	Geometrical characteristic of the network	Sociogram
Quantitative	Numerical values of the network’s metrics	Sociometry

A good example of this categorization is the work done by Segarra et al. (2017) in the search for a trend of the density value according to the number of nodes in the network. The researchers measured the social structure of 8 organizations (architectural firms) for a period of six months in Chile, finding a clear trend for density.

“Density is inversely related to network size: the larger the social network, the lower the density, because the number of possible connections increases rapidly with the number of vertices”(Nooy et al. 2005). This can be easily verified by plotting the function of density. Since density $d(e,n)$ is a function of two variables:

$$d(e,n) = \frac{e}{n \cdot (n-1)}$$

Where:
d is the density of the network;
e is the number of actual edges in the network; and
n the number of nodes in the network

It can be plotted as a 3D surface depending on the number of nodes n and edges e, as Figure 1 shows. The greater the number of nodes, the number of edges that are required to obtain a high density becomes exponentially larger. This mathematical tendency was empirically proven by Segarra: "we observed that the density decreased as the number of nodes increased" (Segarra et al. 2017).

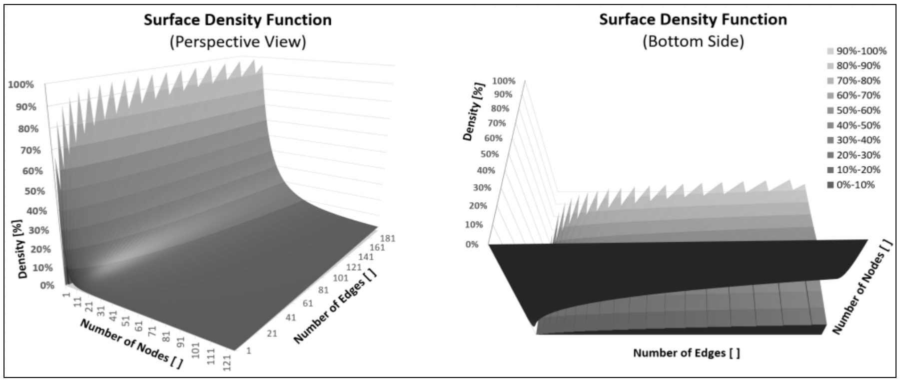


Figure 1: Surface of the Density Function (Perspective and Bottom Views)

What Segarra et al. (2017)found was an 8-points contour line of the shown surface.This density-tendency was found considering a period of six months; in this study the densities were obtained considering a period of three months. When all these values are plotted in the same graph, it seems that European projects and organizations register higher densities. It also seems that the Chilean infrastructure project is located near the points obtained in Chilean organizations, as it is shown in Figure 2.

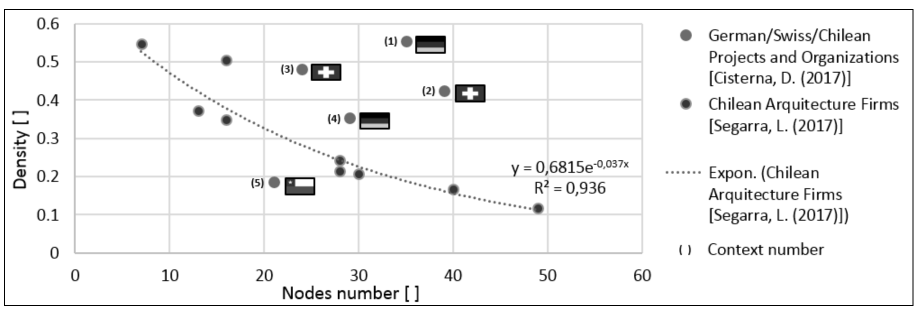


Figure 2: Density vs Number of Nodes. Comparison between Density Values

If the SNA-Instrument comes into use in a regular basis, it will be possible to add new trend lines to Figure 2. These trend lines can be classified by: type of organization (architecture, engineering, construction, consulting, etc.); type of project (industrial, housing, infrastructure, etc.); and, by geographical location. This can be done not only with the density of the networks, but also with all other metrics calculated through algorithms. Each implementation of the SNA-Instrument would feed a database, which will deliver increasingly accurate statistical trends. This database could be used for two purposes: **a) statistical benchmark**, which would make it possible to compare the SNA-metrics, obtained with historical average values, and **b) best practice comparison of SNA-metrics**, which would make it possible to compare the SNA-metrics of a certain project with the SNA-metrics of best practice projects. Considering that the density is directly proportional to the level of communication of the projects, the results of these benchmarks will answer questions such as: a) do projects and organizations in Europe generally have a higher level of communication than in South America? b) Do infrastructure projects generally have a lower level of communication than normal ones?

CONCLUSIONS

The results of the present research work confirm that the application of SNA in construction projects promotes an improvement of information flows, cooperation and mutual trust, because it provides a diagnosis of the social and communicational structure of the project, allowing them to be improved. The SNA-metrics can be used to identify formal and underrated or informal links between project participants, tacit knowledge networks or even network-structures prone to unethical behavior. Significant and meaningful results can be generated for both organizations and projects, especially if the analysis is performed recurrently over time. Even complex project environments, such as big infrastructure projects, can be described well. Such projects in particular usually have great potential for improvement, which can be identified with SNA-metrics. In addition, the metrics allow a cross-project comparison and benchmarking in order to identify best practice applications on the basis of described patterns, e.g. communication and information transfer patterns. The results of the SNA analyses are directly dependent on the openness and participation of the respondents, which is why cultural aspects (company or country) play an important role. Therefore, great importance should be attached to the conviction and involvement of the project participants.

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