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A KNOWLEDGE MAP BASED ON NETWORK ANALYSIS TO SUPPORT ENERGY DECISIONS ON THE CONSTRUCTION PHASE

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Abstract: This study presents a framework to obtain a knowledge map (K-map) to support the decision-making (DM) process of energy estimates of the construction phase of oil and gas projects. The K-map comprises the most impacting construction activities in Brazil and the respective parameters, such as physical systems, design, site characteristics and resource features. The proposed K-map relies on the network representations of three case studies and expert surveys. In addition, the K-map can be updated with knowledge collected from a pilot social network interface, used by specialists and contractors to discuss a real oil and gas project. The K-map can provide the DM with useful correlations, which are concealed in the context of previous projects of the organization and its experts. As part of a larger life cycle energy assessment (LCEA), the proposed K-map can be expanded in the future to improve the DM process of infrastructure facilities in the early stages of the project, by providing more evident scenarios of energy savings during the construction phase and the corresponding trade-offs in the life cycle. The current research is not an energy calculator of the construction phase, but a collaborative tool to allow project team to debate and co-investigate the best means to improve energy consumption.

1 INTRODUCTION

The world has been facing several restrictions on business as usual that will serve to avoid, or at least to mitigate, the global warming effects in the near future. Among other constraints, low energy use and greenhouse gas emissions are considered the most important. To achieve these goals, nations and organizations are faced to curb energy consumption and carbon emissions. In this sense, life cycle energy assessment (LCEA) has demonstrated to be one of the most powerful used tools to account for these impacts (Aragao and El-Diraby, 2015). However, traditional assessors alone may not have the multi-disciplinary knowledge that is required in more complex analyses such as the construction phase of oil and gas projects.

In many energy estimate works, there is a clear attempt to model the different kinds of construction activities as distinct as possible by using a process approach (Aktas and Bilec, 2012; Junnila et al., 2006; Hong et al., 2014; Kim et al., 2014; Davies et al., 2015; Ding and Forsythe, 2013). However, there are numerous construction activities, and the impact of each activity will depend on various factors, such as design parameters, construction site characteristics, and types of resources. This introduces a heavy burden for the assessment because it is utterly time-consuming, if not virtually impossible, to map all construction activities in project sites. Besides, very often the same construction activity is implemented differently in different projects or even in different phases of the same project, depending, for instance, on the present available resources, current site conditions, etc.

In this study, we present a framework for a knowledge map (K-map) approach that will support the decision-making process involving energy estimates of the construction phase of oil and gas projects. The proposed K-map is a collection of relevant knowledge derived from case studies and expert surveys by using Network theory.

The main source of evidence of the case studies are semi-structured interviews. The interview can be understood as an in-depth process, since the participants will be asked open-ended questions so that the interviewer is able to have an holistic idea of the participant's view about the studied projects. According to Berry (1999), semi-structured in-depth interviews suits best this study, since the interviewer is able to focus on the main topic by means of a pre-elaborated list of open-ended questions while probing the interviewee by addressing other questions considered relevant for the topic. The questions are related to challenges, lessons learned, good practices and opportunities that affected or could have affected the energy consumption during the construction phase. Due to the nature of the questions, the participants are led to recall the most impacting factors and activities based on their observations and own participations in the projects. Interpreting and sorting the answers according to the existing thirteen construction activities and factors categories of this research is an important task of the interviewer.

For each case study, we will recruit people who participated in the projects based on three different groups: contractors, owner representatives and owners. It is expected that these groups comprise the main actors that can reconstruct the main facts of the projects. With six or seven participants for each case study, one anticipates reaching the saturation of information (Seidman, 2006:55), in which the interviewer begins to hear the same relevant information reported from different participants, no new fact is added and thus further interviews are unnecessary.

The K-map can be seen as a depository of knowledge which is contextualized in terms of previous projects and relies on experts' experience as well. Furthermore, the K-map will serve as a baseline that can be compared with real-world social networks of project team members, since the organizational knowledge is dynamic and therefore it varies significantly along time. To undertake this collaborative phase, a social network interface (Green 2.0) will be offered for future real-world projects, in which other specialists or stakeholders will participate to discuss and comment on the project. The K-map is intended to present valuable knowledge that will support the DM of future LCEA. It is believed that the DM process will be significantly facilitated instead of assumptions based only on the knowledge of traditional LCA assessors.

2 HOW TO MODEL KNOWLEDGE – NETWORK ANALYSIS

In today's organizational environments, collaborative tools such as social networks are more and more employed because of the value that is aggregated to the final outcome of their processes by means of individual contributions (Gruber, 2008). Moreover, in the current on-line era, in which people want to directly influence organization's decision making, it is fundamental the capacity to take advantage of social networking chaotic discussions and to transform it into a new order that will bring benefits. Also known as the bottom-up decision making process, it takes into consideration the dynamic on-demand community's knowledge and opinions (bottom) to forge the analysis and decision at the higher levels of organizations and governments (up), as opposed to the traditional top-bottom decision making process, in which communities and other stakeholders are not directly involved (El-Diraby, 2011).

Social network analysis (SNA) is a branch of Network theory, which can be traced back to the first studies of Sociometry and Moreno's sociograms (Scott, 2013; Moreno, 1934; Moreno and Jennings, 1938). Sociograms are graphical representations of human interactions, in which the vertices or nodes represent individuals being studied, and the edges or lines represent the connectivity between them. The way the connectivity is defined depends on the study and can be related to communication, friendship, attraction, supportiveness, etc. Using sociograms as a visualization method to analyze small networks (up to some hundreds of nodes) is remarkably useful, since the human eye is quite efficient to recognize patterns and structures. However, analyzing networks of thousands, millions of nodes and edges by using a visualization method is useless, as the graphical representation of large scale networks is limited and therefore the human eye is not able to distinguish overlapped structures (Newman, 2003). SNA has come up to help resolve this limitation. Firstly, built on Graph theory and statistics, SNA evolved from being able to detect the most influential, prestigious or central actors – measures of centrality (Freeman, 1978; Freeman, 1977); to identify hubs and authorities (link analysis); and to discover communities by using community detection algorithms (Oliveira & Gama, 2012).

Nevertheless, networks are not just about individuals. Indeed, the concepts of SNA and Network theory can be extended to any kind of network. Newman (2003) classified real-world networks into four categories: social networks, comprised of people or a group of people; technological networks, which include the infrastructure networks necessary to distribute electricity or other public services; biological networks, such as the network of metabolic pathways of different substances; and information networks or knowledge networks, such as the network of citations among academic articles, the network of webpages on the Internet, or the network of influence of different factors on a specific process.

The network of construction factors (design, site characteristics, resources and physical systems) and construction activities is the scope of this study. We are not only interested in the network of formal knowledge bases (documents, protocols, engineering concepts, standards, etc.) or the network of individuals who have the knowledge, but also in the connectivity of tacit knowledge that can generate a new knowledge, or can influence an existing knowledge or the decision making. In this regard, we define the connectivities (dyads) of the networks of this study according to the level of influence of construction factors and/or construction activities on the energy consumption during the construction phase. In other words, factors and construction activities are connected when they imply a high influence on the energy use.

For example, in the construction of underground pipelines, which can be seen as a physical system, there must have a connection between welding (a construction activity) and the assembly of the buried piping (another construction activity) since a significant amount of energy is spent to provide the thermal energy for the welded joints. However, not all relations are as easy to identify as the example above since the level of influence is contextual; therefore, each project must have its own network of factors/activities that should be defined by factors related to design, site characteristics as well as resources. In the example above, if welding does not influence alone underground pipelines, what are the other factors that significantly affect the energy spent on these projects such as weather, geographical location, type of soil, design parameters (thickness of the pipe) and the capacity of resources among others? Since this knowledge is contextual, any pattern that attempts to describe this phenomenon should rely on previous projects and the tacit knowledge of experts. Although this research aims at collecting, representing and mapping the knowledge of energy use in the construction phase, this framework can be expanded to embrace other disciplines such as cost and schedule due to the contextual nature of construction projects and similar affecting factors and activities.

3 METHODOLOGY

3.1 The activity/factor framework

For the sake of scope delimitation, it is necessary to define the construction activities and factor that will compose this research. Based on past construction sites, we have observed that most construction firms organize their resources (manpower and equipment) into a few number of teams, which are not necessarily assigned to just one construction activity. In fact, construction managers routinely combine their teams, which perform basic construction activities (excavation, concrete preparation, welding, etc.), to undertake more complex activities (tank assembly, SCADA assembly/test, etc.) during the project. This observation implies that any construction work can be described as a combination of basic works that are delivered by the construction teams. In this regard, the impact of all activities will be a combination of the impact of each basic activity.

A tank assembly is a good example to illustrate the assertion above. Depending on the level of detail of a schedule, the assembly of a tank can be seen as just one activity, even though the construction manager is aware that this activity is comprised of different phases or basic activities. First, *earthworks* are necessary to level the terrain on which the tank will be erected. Second, the *excavation* team must open the pit where the foundation of the tank will be constructed. After that, the *concrete preparation* team will provide the forming, rebar assembly and concrete pouring, so that the final foundation is ready to support the assembly of the tank. Then, the tank steel plates are transported by an *onsite transportation* team from the construction warehouse to the location where the assembly will take place. After that, there must have a *rigging team* that will be in charge of positioning the parts at the right location, so that the welding team will weld the steel plates according to the design and quality requirements. In the example above, we mentioned five basic activities that were combined to perform a more complex activity, called tank assembly. However, the basic teams are not only responsible for the tank assembly. They may be indeed allocated to other activities according to the project schedule. Finding the impact of these five activities means that the impact of the tank assembly is known as well. Based on the author's observation and experience, thirteen basic construction activities of the oil and gas domain compose this research and are presented on Figure 1.

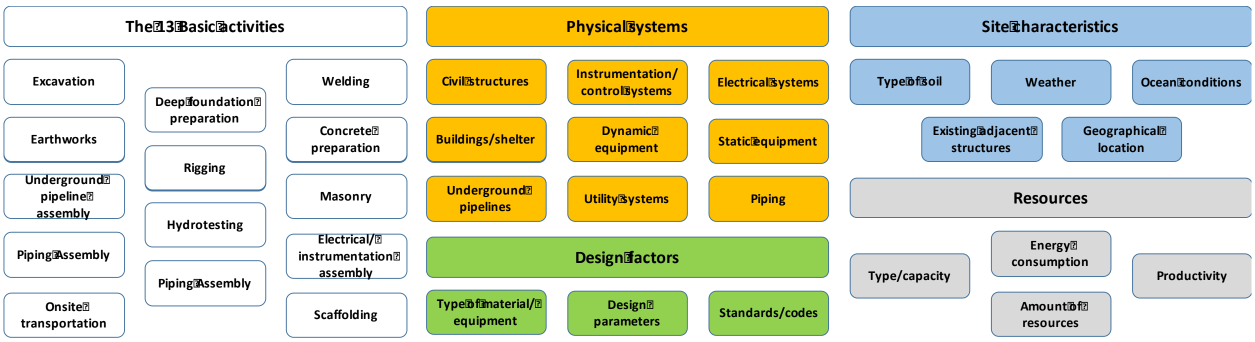

Figure 1 - The thirteen construction activities and the four categories of construction factors used in this study.

Several factors drive the performance of construction activities. These factors serve as the boundary conditions of construction projects, and any comprehensive assessment should ever consider their effects on the DM of the project. Thus, mapping the main factors that mostly influence the construction activities and how they closely interact to each other to form a network of construction factors/activities falls under the umbrella of this research. Based on previous observations, Figure 1 also illustrates the four categories of factors that influence the energy use of thirteen construction activities presented above.

Identifying the relations between these factors and activities is not always trivial. As other relations cited above, this connectivity is very often contextual and therefore it depends on the project. In principle, a factor may influence any construction activity and any other factor. In addition, the connections in the figure are represented with double arrows to indicate that a hypothetical factor "x" can influence other factor "y", but "y" can influence "x" likewise so that the direction of what influences what matters in this study. Of course, we will discuss later on that the direction of some connections are illogical and should be removed from the study. For instance, the weather, defined as a site characteristic, can influence excavation, a construction activity; but it is difficult to imagine, however, how excavation can influence the weather.

As in many other examples, these connections can be obtained from the tacit knowledge of experts and professionals who work in construction projects. Indeed, finding a framework that is able to collect, represent, analyze, filter and map these connections can guide the decision-making process during the early stages of projects.

3.2 Capturing the domain knowledge – case studies

The domain of this study is the oil and gas sector; thus previous oil and gas projects are used as case studies. In addition, semi-structured in-depth interviews are used to collect the participants' main facts of the projects. The information extracted from the interviews will be transcripted, and the responses will be analyzed in a way that the relations between factors and activities are collected and represented according to the adjacency matrix (see section 3.1 and Table 1). The interviews will form the main piece of evidence of the case studies.

3.3 Capturing the domain knowledge – surveys

The purpose of conducting this survey is to collect the general knowledge of the participants regarding the influence of thirteen construction activities, physical systems, design factors, construction site characteristics and resources features on the energy use during the construction. The survey will be conducted by means of close-ended questions, which will cover the four categories of factors cited above, and the corresponding thirteen construction activities.

As opposed to the interview phase, the participants, peers of the construction industry, will not be recruited according to a particular project, as one of the main goals of the survey is to collect the general knowledge of the participants, regardless of any specific project experience. As with the interview phase, the participants will be proportionally selected according to the three groups presented in section 3.2.

Initially the possible number of questions is calculated considering all types of connections, which results in a matrix 34 x 34 in dimension or 1156 possible connections. However, many questions should be eliminated as there are inconsistent dyads based on interpretation or assumptions, which are listed below.

- Activities can only be affected by other activities, design, site characteristics and resources features. Physical systems cannot affect or influence activities because we are assuming there is always a relation activity/design related to a system that predominates first.
- The construction of physical systems can only be affected by activities. Physical systems cannot affect other physical systems, similar to the first assumption. In addition, design, site and resources cannot affect a system since they affect the corresponding activities first.
- Activities and resources cannot affect design.
- Site characteristics are only cause and therefore they cannot be affected by any other activity or factor.
- Resources can be affected by any factor or activity, except for physical systems. Our assumption, in this case, is that there is always a relation between the corresponding activities and design, site and resources that is predominant first.
- The self-connections between activities and factors is not possible. Welding cannot affect welding, weather cannot affect weather, etc.

The matricial representation of all connections is called adjacency matrix (Jeong et al., 2015) and is illustrated in Table 1. Similar to a cause an affect matrix, the rows are the affected terms and the columns are the causal activities/factors. The adjacency matrix is the standard mathematical representation in network analysis and it is the basis for the calculation of most measures and indicators. In this study, it is a binary matrix, in which the numbers 1 and 0 represent the presence or absence of a connection, respectively. After eliminating the connections by interpreting the assumptions above, the number of possible connections was reduced from 1156 to 573. The questions are multiple choice in the form of statements, in which the respondents will answer according to an intensity rating scale (no effect/low effect/moderate effect/high effect). In this sense, the connectivity between two nodes can be defined according to a cut-off criterion that, for example, is based on the statistical mode of all responses being at least “moderate effect”. Three examples of questions are listed below.

- Excavation affects the energy use during the construction of utility systems.
- Welding affects the energy use during the assembly of piping.
- Weather affects the energy use of earthworks.

Table 1 - Adjacency matrix of the thirteen activities and four factors categories. The cells checked with an "x" were eliminated by using the assumption on section 3.3.

Categories	Types		Activities													Physical systems									Design features			Site characteristics					Resources features			
			Excavation (not included in earthworks)	Deep foundation preparation (drilling, hammering, etc.)	Welding	Piping assembly	Earthworks	Rigging	Concrete preparation (forming, rebar assembly, concrete pooring, etc.)	Electrical and instrumentation assembly	Underground pipeline assembly (stringing, bending, welding support, lowering, backfilling and	Hydrotesting	Masonry	Onsite transportation	Scaffolding	Civil structures	Building/shelter	Static equipment (tank or vessel)	Underground Pipeline	Piping	Electrical equipment	Instruments	Dynamic equipment (pumps, compressors, turbines, etc.)	Utility sets (generator, air compressor units, steam units, hydraulic units, etc.)	Type of material/equipment	Design parameters	Standard/Code	Soil	Ocean conditions	Weather	Adjacent structures	Geographical Location	Type/Capacity	Energy consumption	Productivity	Quantity
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Activities	Excavation (not included in earthworks)	1	x													x	x	x	x	x	x	x	x	x												
	Deep foundation preparation (drilling, hammering, etc.)	2		x												x	x	x	x	x	x	x	x	x												
	Welding	3			x											x	x	x	x	x	x	x	x	x												
	Piping assembly	4				x										x	x	x	x	x	x	x	x	x												
	Earthworks	5					x									x	x	x	x	x	x	x	x	x												
	Rigging	6						x								x	x	x	x	x	x	x	x	x												
	Concrete preparation (forming, rebar assembly, concrete pooring, etc.)	7							x							x	x	x	x	x	x	x	x	x												
	Electrical and instrumentation assembly	8								x						x	x	x	x	x	x	x	x	x												
	Underground pipeline assembly (stringing, bending, welding support, lowering, backfilling and crossings)	9									x					x	x	x	x	x	x	x	x	x												
	Hydrotesting	10										x				x	x	x	x	x	x	x	x	x												
	Masonry	11											x			x	x	x	x	x	x	x	x	x												
	Onsite transportation	12												x		x	x	x	x	x	x	x	x	x												
	Scaffolding	13													x	x	x	x	x	x	x	x	x	x												
Physical systems	Civil structures	14														x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Building/shelter	15														x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Static equipment (tanks, pressure vessels, etc.)	16														x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Underground Pipeline	17														x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Piping	18														x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Electrical equipment	19														x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Instrument/control system	20														x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Dynamic equipment (pumps, compressors, turbines, etc.)	21														x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Utility sets (generator, air compressor units, steam units, hydraulic units, etc.)	22														x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Design	Type of material/equipment	23	x	x	x	x	x	x	x	x	x	x	x	x	x										x								x	x	x	x
	Design parameters (load, thickness, pressure, temperature, etc.)	24	x	x	x	x	x	x	x	x	x	x	x	x	x											x							x	x	x	x
	Standard/Code	25	x	x	x	x	x	x	x	x	x	x	x	x	x												x						x	x	x	x
Site characteristics	Soil	26	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Ocean conditions	27	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Weather	28	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Adjacent structures	29	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Geographical Location	30	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Resources	Type/Capacity	31														x	x	x	x	x	x	x	x	x									x			
	Energy consumption	32														x	x	x	x	x	x	x	x	x										x		
	Productivity	33														x	x	x	x	x	x	x	x	x											x	
	Quantity	34														x	x	x	x	x	x	x	x	x												x

3.4 Modelling the networks

Before modelling the networks, some definitions should be introduced. The relational database obtained from the interviews and the surveys is used to represent a network of factors and activities in a commercial network analysis interface. During the representation of the networks, the activities and factors are the nodes, and the edges are the connections between them, which is defined according to the influence on the energy consumption during the construction phase. The direction of the connectivity matters in this study so these are directed networks (Oliveira and Gama, 2012), as opposed to undirected networks. Using the example from the previous section, the weather may affect the energy use of earthworks but the opposite statement is impossible.

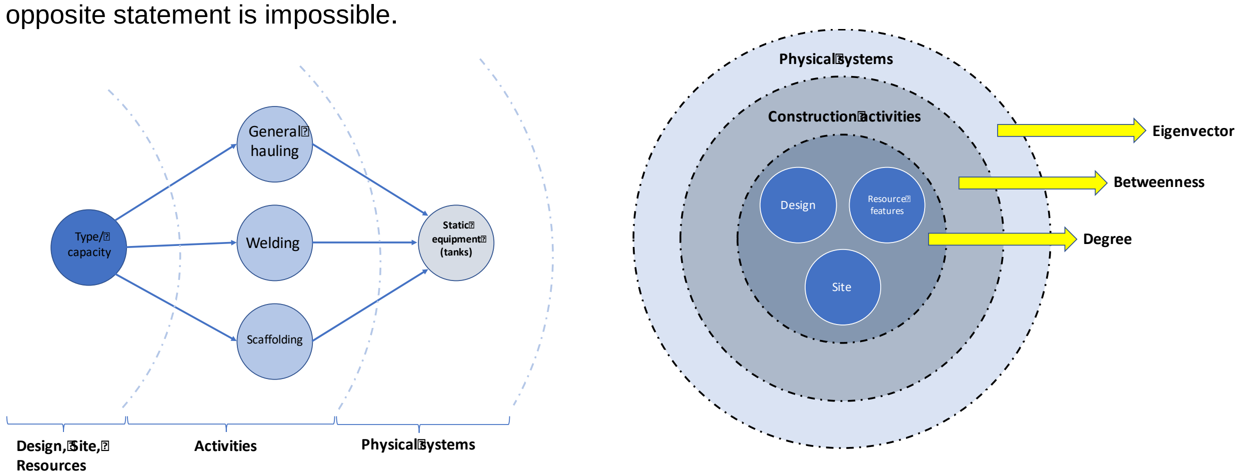

Figure 2 - The schematic representation of the example of the tank in section 3.1 (left), the hierarchical layers of the networks modelling and the centrality measures used to identify the most influential factors and activities (right).

The assumptions adopted in section 3.3 are also used to define the structure of the networks based on the possible paths connecting the nodes. Physical systems can only be connected from construction activities, which can also be connected from three categories of factors: design, resources and site characteristics. In addition, these three categories can be connected in several different ways in the network. The illustration in Figure 2 represents the example of the tank in section 3.1 and the general structure of these networks with three different layers. In the inner layer, we can see the factors pertaining to design, resources and site characteristics with many possible connections between each other and, likewise, with nodes of the intermediate layer. The construction activity nodes in the intermediate layer are the “bridge” nodes linking the inner layer with the outer layer, where the physical systems nodes are located.

By using this structure and some centrality measures of network analysis, relevant patterns of the network can be identified. As an example, similar to what proposed Jeong et al. (2015), degree, betweenness and eigenvector centrality measures (Oliveira and Gama, 2012) can be used to identify the most influential nodes (or factors) in each layers, and then the most important paths, or combination of factors, that mostly affects the energy consumption of the construction phase. These combination of factors, which are unique for each project, is a significant knowledge that is worth being incorporated either in LCEA’s in the early stages of projects or in any other decision-making process during the construction phase.

3.5 Comparing case study and survey networks

The surveys are based on the general knowledge of the construction professionals; the interviews rely on case studies of real-world projects. Each method has pros and cons that should be carefully evaluated first. Because the interviews tackle actual projects, one expects that the network representation closely relates to that particular project, which means networks of different projects will unlikely have similar representations as they hold unique circumstances. Moreover, the nature of open-ended questions in semi-structured interviews suits best the data collection of specific projects because it provides the interviewer the possibility to probe the interviewees, seeking more specific situations related to the topic. Since the interviewees are exposed to a context closely linked to the project, they will likely thrive on recalling the main facts observed during the construction and therefore pointing out valuable connections and knowledge for the research. However, the responses need to be interpreted to achieve the data collection and this method phase may be subject to mistakes or even bias.

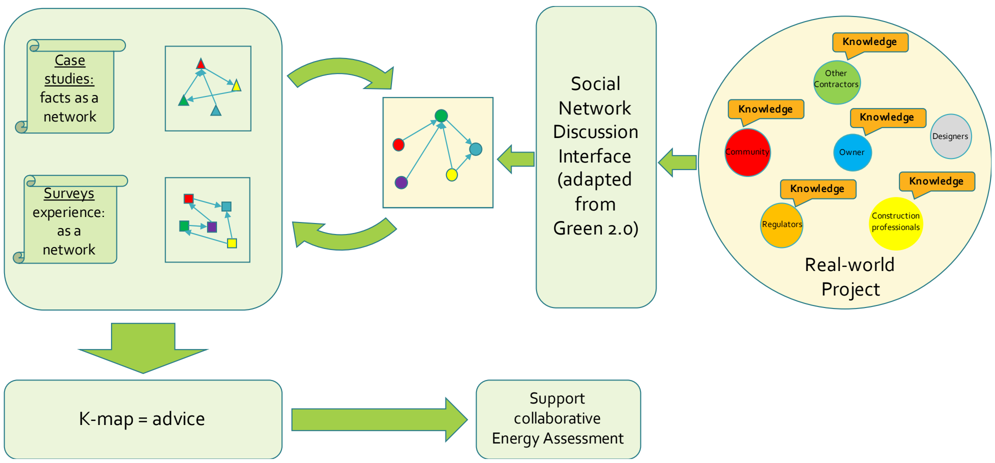

Figure 3 - Application of the proposed K-map and the support of a social network discussion interface (Green 2.0) in real-world projects.

In contrast to the interviews, the main goal of the survey is to collect the general knowledge of construction experts, not only focusing on any particular project. The rationale in this case is to take advantage of the professionals' entire experience, expanding the network in terms of depth and breadth. The survey is a questionnaire of multiple choice questions with a rating scale, in which the participants will choose the intensity of the relation between factors and activities based on their experience. Hence, the greatest advantage of the surveys relies on providing depth to the domain with a relatively smaller participants' burden. However, surveys are prone to the recall bias (Rice et al., 2014), in which the participants are just able to remember a few facts due to the lack of a context and probing.

That said, the survey and the interview methods are complementary, which means both networks can be interpreted and analyzed according to one of following hypotheses.

1. The network of surveys may be seen as a general baseline as it is based on the general knowledge of participants; therefore, the networks of case studies are particular pathways of the survey networks.

2. As long as the case studies are representative of the domain in terms of quantity and variety, both networks can be combined so that the resulting network best represents the domain.

3. There is no evidence that the networks can be combined or else one can stems from the other. In this case, the analyses will have to be conducted separately.

Even in case of hypothesis number 3 is confirmed and the other two are ruled out, one believes that the collected knowledge will be still relevant for the domain because of the comprehensiveness feature of both methods of data collection.

3.6 The Knowledge map

The decision making (DM) lacks information during the first phases of projects, which leads to uncertainty, unknown risks and sometimes poor decisions. As mentioned above, LCA is a powerful DM tool that highly depends on assumptions. However, the lack of knowledge can also lead to poor assumptions in LCA. In order to make better assumptions and improve the DM process, this study proposes the development of a tool that is able to collect, analyze, represent and map relevant knowledge, based on past projects and professionals of the construction industry. According to Grey's (1999) definition, a K-map is a dynamic tool to help organizations map “the location, ownership, value and use of knowledge, to learn the roles and expertise of people, to identify constraints to the flow of knowledge, and to highlight opportunities to leverage existing knowledge.” Grey visualizes a K-map as dynamic, and so is knowledge. Best practices, lessons learned and new technologies are circumstantial, and it evolves as the organization conducts more projects and professionals collaborate to achieve the goals of the organizations.

In this sense, Figure 3 shows a schematic representation of the proposed K-map and its application in real-world projects. In the analytics module, the networks from case studies and surveys are interpreted using network theory and then the newly-generated knowledge feeds the knowledge map, which will lead to wiser assumptions and will support the DM process in the early stage of projects. However, even during the construction phase, the K-map can be coupled with a social network interface of a real-world project, in which project team members, regulators and community can discuss and collaborate on several issues of the project. The DM of the construction phase can not only benefit from the K-map and from the knowledge collected from the social network discussion, but it can also provide knowledge to expand or update the K-map of the organization. This feedback system is able to deal with the dynamism of knowledge in organizations. This research will benefit from an existing social network interface, Green 2.0 (Canarie, 2016), designed to allow project participants discuss energy savings in buildings. As part of the last phase of this research, Green 2.0 will be adapted to work with oil and gas projects as well as to encompass the scope of construction activities and projects factors, as presented in section 3.1.

4 CONCLUSION

LCEA has been widely used to account for environmental impacts. However, traditional LCA is built on assumptions that are not necessarily aligned with the most relevant knowledge of the organization. Moreover, in a carbon economy, construction parties, including contractors, will have to either manage energy consumption better or lose money.

As such, this research proposes a knowledge map (K-map) to guide the decision-making of energy scenarios in the early stages of projects as well as in the construction phase. The knowledge contained in the K-map is retrieved from two qualitative methods: case studies and surveys. Construction activities and factors are represented as the nodes of a construction network, whose edges (or links) are set between nodes that significantly affects the energy use during the construction phase. By applying network analysis, the networks of particular case studies are examined along with the generic network, whose data is collected from the online survey. After these two phases, one expects to gather valuable knowledge, which is concealed in previous projects and eventually retained by members of the organization. In addition, the K-map can be seen as a baseline that can be compared with social network discussions of real-world oil and gas project teams, communities and other stakeholders. In this sense, the K-map is not only part of the DM process of the front-loading stage, but also supports the construction phase. Furthermore, since the knowledge of an organization is dynamic, the K-map can be updated to incorporate the new knowledge of projects. In order to achieve this collaborative phase, this research will offer an adaptation of Green 2.0, a social network application created to foster discussions and energy savings of building projects.

Finally, the application of this research goes beyond calculating the energy use of the construction phase. It supports the DM of LCEAs with better assumptions as well as it provides a collaborative environment to allow project team to debate and co-investigate the best means to improve energy consumption during the construction phase. In future, besides energy consumption, the proposed scheme is flexible enough so that it can be adapted to accommodate other decision variables such as cost and schedule.

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