DIGITAL INTERACTION PATTERNS ON CONSTRUCTION PROJECTS: A STUDY OF DYNAMIC APPROVAL PROCESSES

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ABSTRACT

As project delivery becomes increasingly digitally-enabled, there are new opportunities to analyse interaction patterns on construction projects directly from digital collaboration systems. Previous research that uses social network analysis (SNA) to map interactions on construction projects relies on survey data. The aim of this research is to use SNA to examine the pattern of interactions involved in approvals processes on a digitally-enabled infrastructure project using data collected from a collaboration extranet. This web-based collaboration system is used to manage information exchange in the approval process. The data is analysed through the use of Gephi, SNA software to visualise and analyse the interaction networks. The paper describes preliminary analyses of the extent of interaction around 23 kinds of documents; showing a social network analysis of the pattern of digital interactions around the contract documents. Two network analyses are conducted to show interactions between project stakeholders, and between these project stakeholders and the digital documents. The next steps in the research are to compare the findings of this analysis with qualitative data from the project, to refine the techniques for data retrieval to analyse interaction patterns on further projects, and to compare and contrast findings across projects.

Keywords: digitally-enabled construction project, social network analysis (SNA), interactions, information exchange, collaboration system

1. INTRODUCTION

As project delivery is becoming increasingly digitally-enabled, information is reshaping management practices, relationships and work-processes (Whyte and Levitt 2011). In the UK construction industry, a government report calls for adopting BIM in construction practices to achieve successful supply-chain integration for *"the accuracy, effective flow and intelligent use of information"* (CIC. 2011: 91). This generation of large datasets raises new research opportunities. Researchers of construction IT use visual analytics to analysis stakeholder interests and documents on construction projects (Russell et al. 2009) using techniques to access data for decision-making developed in research on On-Line Analytical Processing (OLAPCouncil 1997). Such work has also automated ways to access electronic documents (Caldas and Soibelman 2003), and coupled information repositories with decision support systems (Chau et al. 2003). Yet such studies do not use digital datasets to analyse patterns of social interactions.

There is also a rich tradition of research that maps interactions in construction projects using social network analysis (SNA) (Loosemore 1998, Chinowsky et al. 2008, Chinowsky et al. 2009). Chinowsky et al (2008) develop a social network model for construction projects approaching high performance in cost, schedule, and quality. Researchers have used the SNA method to examine *knowledge networks* (Criscuolo et al. 2007, Gomez and Pryke 2009, Javernick-Will 2011), *information exchange networks* (Pryke 2004, Pryke 2012), *communication networks* (Hossain 2009, Chandra and Loosemore 2011, Larsen 2011), *project organizational relationships* (Li et al. 2011). However, despite the highly digitalised working space employed in large scaled and complex construction projects, most of this network analysis research has continued to rely on survey data, collected by the researchers to understand patterns of interaction/ networks in projects and associated organizations.

This research contributes to this SNA tradition by examining the pattern of interactions involved in approvals processes on a digitally-enabled infrastructure project using data collected from a web-based collaboration system. The focus is on interactions within a real digitally-enabled approval processes. The next section considers the literature on digitally-enabled construction projects; information exchange and SNA of interactions. The following section describes the methods used for data collection from a digital collaboration system and the analysis of this system, both descriptively and using SNA. The preliminary findings are then discussed, with an overview of the types of documents and activities on the project, and a map of the pattern of interactions around one of these document types, the contract documents. The paper finishes by discussing this work, drawing conclusions and articulating the next steps for this research.

2. LITERATURE REVIEW

2.1 Digitally-enabled construction projects

In this paper, digitally-enabled construction projects refer to projects that implement digital collaboration technologies to manage project information. The fragmented nature of construction industry leads to a complex communication structure on projects, which is the barrier to effective collaboration (Arnold and Javernick-Will 2013). Implementing digital collaboration technologies on projects is of interest to researchers. The digital collaboration technology has been studied as web-based project management, web-based construction project management system, and project management software system.

Web-based project management is one of technological integration approaches to addressing the increasing complexity of projects (Alshawi and Ingirige 2003). Nitithamyong and Skibniewski (2004) identify factors that affect the performance of implementing web-based construction project management system, and in a follow-up study, they confirms these factors and also develop measures, which can be used to evaluate the system performance (Nitithamyong and Skibniewski 2006). Recent research highlights the integration of information is as important as technology integration in achieving effective collaboration. Arnold and Javernick-Will (2013) argue that a more collaborative and inclusive implementation of project management software system will reduce data reentry and enhance efficiency in engaging with information, by increasing sharing access to integrate more external information into the central information repository. However, the increase of access will challenge the information exchange activities within the software system.

2.2 Information exchange

Information exchange is specially coupled with tasks execution, and is "one of the measurable characteristics that affect project performance" (Chinowsky et al. 2008: 808). In digitally-enabled projects, information management activities are defined as "the activities involved in shaping the flow of data, information, and knowledge" (Whyte and Levitt 2011: 367). More specifically, in this research , digitally-enabled information activities refer to information exchange activities within the digital collaboration technology, and interactions are considered as the basic unit that constitute these activities. Information exchange network is understood as the interaction pattern. Normally, this is a challenge to project network research for the commonly adopted survey approach of data collection(Chinowsky et al. 2008). After the determined explanation of information exchange and interactions, an associated question arises: how to measure them?

Scholars argue that there are two directions for information exchange within organizations (Daft and Lengel 1983), the vertical direction is conduct to interpret external environment, which can be understood as interactions between manager and employee, and the horizontal direction is conduct to coordinate internal work that can be considered as interactions between actors on the same level. In actual project process, these two directions are not able to simply divide for analysis but always appear jointly. While the social network model incorporate this division and outlines a different scenario. Chinowsky et al. (2009) interpret these two information exchange directions as the issues of *Leadership* and *Collaboration*, which affect to high project performance. The leadership perspective is emphasised on the individual performance within a network fosters team collaboration. The collaboration perspective is focused on overall network performance.

2.3 Social network analysis of interactions in construction

There is a rich tradition of research that using SNA concepts to understand organizations dates back to 1950s (Tichy et al. 1979). And in construction organizations and projects studies, this research tradition have been applied and developed rapidly in the past 15 years (Chinowsky and Taylor 2012). Scholars argue that it is important to deal with task dependency, structural analysis, process mapping and many other issues in construction (Pryke 2012). For examples, global intra-organizational knowledge exchange network has been studied to understand how knowledge connections were formed across geographical boundaries, using measure of density to quantify the amount of reliance of particular actor had on their knowledge sharing connections (Javernick-Will 2011); information exchange network has been studied as formal collaboration to provide an alternative approach to the traditional focus on time, cost and quality, and measure of socio-graph is adopted to interpret network gaps and client's satisfaction (El-Sheikh and Pryke 2010); and communication network has been studied by analysing emails directly to understand communication and coordination in construction projects, combined measures of centrality and strength of social ties are adopted to measure project coordination (Hossain 2009). Network analysis researchers adopting several key concepts (e.g. Centrality (Freeman 1978)) from established graph theory as mathematical solutions for analysing quantitative relationship.

Diverse measures can automatically be provide by SNA software, such as UCINET (Borgatti et al. 2002)and Gephi (Bastian et al. 2009). This research effort currently focus on Degree centrality, Betweenness centrality, Strength of tie, Network density (see Table 1) and will expend to indicators, such as attribute of Time interval (Bastian et al. 2009) for dynamic analysis. Table 1 depict these selected measures and their descriptions from literature, and how these measures applied in this research to understand the interaction performance of both individual actors and entire network.

Table 1: List of measures selected in this research for SNA.

Measures	Description from literature	Mobilization within the data
Degree centrality	Measures how many edges dose each node have in the network. (Freeman 1978)	It is a key measure to indicate the total count of social relationships of each actors.
Betweenness centrality	Measures how often a node appears on shortest paths between nodes in the network. (Brandes 2001)	It is a variable measures the amount of information that is routed through an individual during the exchanging process.
Strength of tie	Measures the weight of edges in the network. (Granovetter 1973)	It is a calculation of how many interactions between every two actors.
Network density	Measures how close the network is to complete. A complete graph has all possible edges and density equal to 1. (Coleman and Moré 1983)	It is a measure to indicate the percentage of existing social relationships from an complete network.

3. RESEARCH DESIGN AND METHODS

3.1 Research design

This research is being conducted in collaboration with the system developer of a well-known web-based project collaboration system and one of their major customers. The digital collaboration system enables users to quickly store, find and share project information. Through collaboration, this research gained access to data on interactions around digital documents on customer projects. It is currently ongoing, and the overall research design has 6 steps:

- Research set-up. This involved set-up meetings with both the system developer and their customer, and a workshop at the system developer offices to explain the research design and outputs.
- Data retrieval from the system database and preliminary analysis. This step involves establishing how to export data to address the research questions; cleaning the data-set and describing it descriptively.
- Social network analysis. The information exchanging network within the collaboration tool can be shaped and represented by the pattern of interactions. Implementing social network approaches in understanding information exchanging network through the digitally-enabled approval processes.
- Contextual understanding. This step is to merge the content data with the network data to interpret the real interactions, relationships and performance of the approval process.
- Identify key actors from different projects for interview and conduct semi-structured interviews with these participants.
- Cross-case analysis. This step is compare and contrast results between different projects for evaluation.

This paper reports the findings of the first 3 steps of this research for one infrastructure project.

3.2 Method of data collection

The data of this research are drawn from Thames Water projects that are successfully delivered through Business Collaborator. Data was collected on interactions around digital documents from the web-based project collaboration system, which is called Business Collaborator and provided by UNIT4. These project interactions take place in the delivery of a Thames Water's infrastructure project , on which this collaboration technology has been used for dynamic approvals, to enable a construction client to track project progress. This research focuses on interactions draws on network analysis theory (Tichy et al. 1979). However, rather than asking individuals to summarise their interactions over the studied period and for certain content areas as is common in social network studies, where for example, Pryke (2012) uses a pre-designed SNA questionnaire to obtain empirical data by surveying participants from project organizations in construction, the source of data of this research provides access to the actual interactions through the digital collaboration system used on the project.

In order to pull out the most appropriate data from selected projects, a trial report is produced initially from one project for this preliminary study. This approach will be refined and used to collect further empirical data on interactions on other projects. This paper reports on the analyses of the trial report.

3.3 Method of data analysis

The first task of data analysis was familiarisation with the project report, which was extracted from the system, and descriptive analyses to determine the approval processes related documents. The data within the report contains rich information for SNA, because several conversations have been carried out with an experienced stuff from the system developer to modify the template of headings. This report was not, however, as rich as expected in explaining the content of different documents. Therefore further contextual information is needed to interpret the digitally-enabled interactions. The descriptive analysis classifies documents in two different categories: Document Type (given in the report) and Reason for Interactions (reasons are given in the report but mixed with usernames. So the data should be reorganized to extract the main reasons for each documents and present in a separate column, then using a Pivot Table to visualised the distribution of documents with these two categories (refer to Table 2). The document distribution table is used to choose the most appropriate documents to understand the digitally-enabled approval processes.

The second task is to identify the pattern of interactions within these appropriate documents. The report format was reorganized to present the distribution of interactions in another pivot table, which was then input into a network pattern using Gephi, which is a SNA tool (Bastian et al. 2009). This is a free SNA software, which is chosen for use in this research as it is good for analyzing huge and complex networks. Interactions of Contract documents have been analysed at this stage.

4. PRELIMINARY FINDINGS

4.1 Determining relevant documents

The reported project is an infrastructure construction project, which started in November 2010 and was completed in March 2013. 554 individual participants were involved in interactions in the digital collaboration system and they processed 833 documents, each of which went through various versions, throughout the whole project. Different types of documents are processed in the tool for different purposes, so initially it is using two categories of 'Artefact type' (document type) and 'Reason for issues' (processing purpose) to classify documents and layout their distributions (see Table 2).

Table 2: Distribution of documents.

Reason for issue / Artefact type	For Action	For Action /FYI	For Approval	For Approval /FYI	For Approval /FYI/Comment	For Comment	For Comment /FYI	For Handover	FYI	For Archival	Grand Total	Interactive documents percentage
Agenda and Minutes	1	1	2			2			29	5	40	87.50%
Assessments, Registers & Schedules	5	8	2			23	2		4	6	50	88.00%
Audit		1	2								3	100.00%
Calculation					2	1			4	1	8	87.50%
Contract		3	1	13	27						44	100.00%
Correspondence	21	16		2	5	2	5		21	1	73	98.63%
Default Object										11	11	0.00%
Drawing	10	71	36			40	1		12	29	199	85.43%
EES Datasheet (DES3)										2	2	0.00%
Manual		1		2			1	1	20	3	28	89.29%
Notice, Permit & Permission	1	3	13	47	25				7	100	196	48.98%
Pending										2	2	0.00%
Photograph									1		1	100.00%
Presentation										3	3	0.00%
Programme & Delivery Plan	23	2	1			1	1		18	1	47	97.87%
Report	10	1	4	3	1	7	2		18	4	50	92.00%
Request For Information (RFI)		7					3				10	100.00%
Review - Gateway etc.	1		9						1	1	12	91.67%
Specification & Brief			1		1	1			6		9	100.00%
Survey		1		2			1		1		5	100.00%
Technical Query (TQ)	9	20	1	3	2		3				38	100.00%
Template (CDP Form)									1		1	100.00%
Test Result, Cert. & Evidence of Legal Compliance									1		1	100.00%
Grand Total	81	135	72	72	63	77	19	1	144	169	833	79.71%

In Table 2, there are 23 types of documents and 6 types of purposes of all these 833 documents. Some of the columns are labeled by combined reasons, for examples, 'For Action/FYI' means these documents are exchanged both for actions and for your information. The reason, 'For Archival', is not in the database originally, but is determined during analyses. It represents those documents that are only uploaded and saved to the system without any further exchange. The 'Interactive documents percentage' is obtained from the result of 'Grand total' subtract

‘For archival’, then divided by the corresponding ‘Grand total’. It shows the proportion of interactive documents in different types documents and is used to re-classify and filter types of documents that are not actually relevant.

As shown in Table 2, 4 types of documents have no interactions at all (under ‘For archival’): ‘Default object’, ‘EES Datasheet (DES3)’, ‘Pending’, and ‘Presentation’. 6 types of documents are 100% interactive documents but with small amount that is less than 10: such as ‘Audit’, ‘Photograph’, and ‘Survey’. Opposite to these above, 3 types of documents are distinctive in understanding the dynamic approval processes, which are ‘Contract’, ‘Drawing’, and ‘Notice, Permit & Permission’(highlighted in grey in the Artefact type column, in Table 2). These three types of document are selected for different focuses and different research assumptions.

Contract – All ‘Contract’ documents are interactive, and 41 documents out of 44 are involved in the approval processes. This type of documents is engaged in the system mainly for approval.

Drawing – Compared to ‘Contract’ documents, there are far more ‘Drawing’ documents are exchanged in the system, but less of them are involved in the approval processes. The main purpose is exchanging comments and distributing actions to improve drawings.

Notice, Permit & Permission – Less than half of this type of documents have been exchanged for further interactions. 85 documents out of 96 are involved in approval processes, and most of them are dealing with emerging issues.

According to the design of the collaboration system, each interaction can have one processing purpose, while in the document level, multi purposes might be carried out. For example, one document can be sent out to different actors for different purposes, some are required to comment while others might be required for actions. Then it moves to the interaction level, learning how the basic unit constitute the approval processes with ‘Contract’ documents (highlighted in grey in Table 2).

4.2 Identifying interaction pattern around ‘Contract’ documents

In Contract documents, each interaction is positioned in its Processing purpose category and visualised in two networks: *Actor interaction network* (Figure 1) and *Document-actor interaction network* (Figure 3).

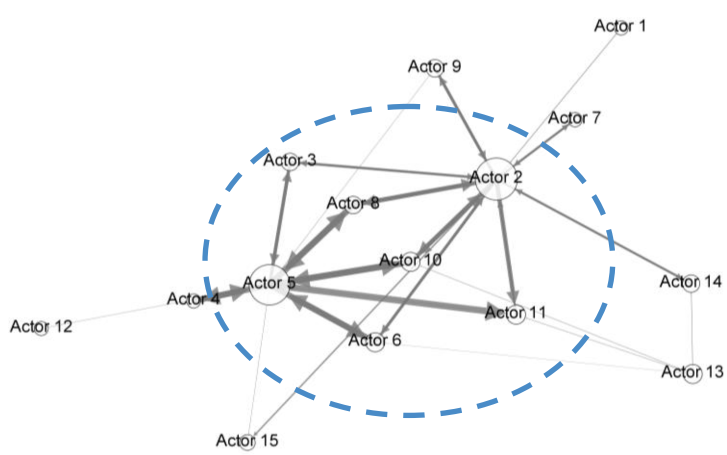

Figure 1: Socio-graph of actor interaction network.

As Figure 1 shows, in the Actor interaction network, nodes are defined as actors, and edges are defined as information exchanges between actors (e.g. Actor 1 send out an issue request for certain purpose with particular document to Actor 2, or Actor 2 response to Actor 1’s send out request). This network map is presenting the direct and indirect relationships between actors in the contract document working process, degree centrality is measuring the individual connectivity within the network, and edge weight is measuring the strength of social tie between actors. The size of the nodes also depicts the degree of centrality results and the thickness of edges shows the strength of social tie. Dashed circle depict the core of the network. The core of the network is mainly based on Actor 5 and 2, but connected by other 5 actors. In the core, Actor 5 and 2 have the largest size in the figure, which means they have the most connections in the network. The strength of social tie measurement (see Figure 2) shows Actor 5 interacts more frequently than Actor 2 to other 5 actors within the core.

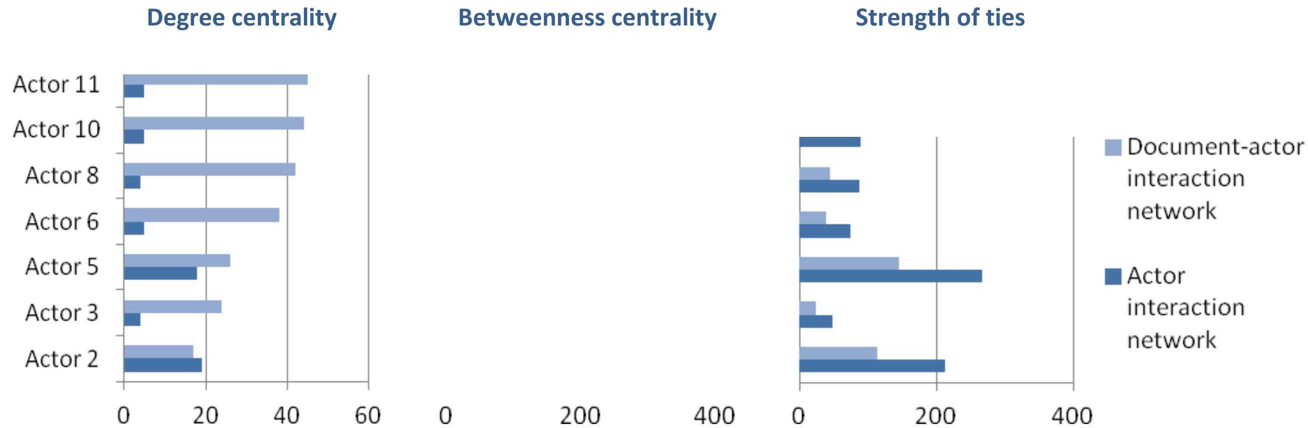

Figure 2: Measurements of core actors for both networks.

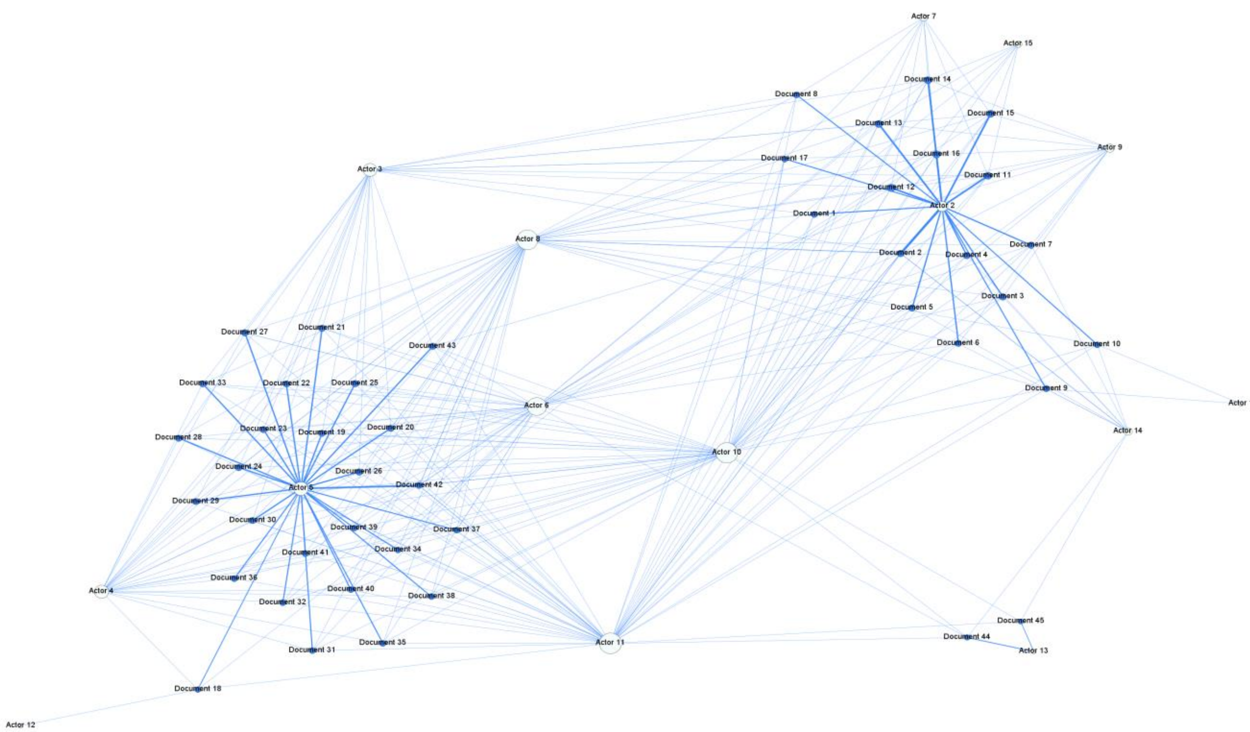

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Figure 3: Socio-graph of document-actor interaction network

As Figure 3 shows, in the Document-actor interaction network, nodes are defined as actors and documents, and edges are defined as relationship between documents and their associated actors (e.g. if Actor 1 send out an issue request for certain purpose with Document A to Actor 2, there is an interactive relationship between Actor 1 and Document A, and an interactive relationship between Document A and Actor 2). This network map is presenting how documents engaged in the interactions between actors, degree centrality is visualising the connectivity of nodes, and edge weight measures are taken as well to measure the strength of the connection between documents and their associated actors. From the socio-graph, it shows that when documents engaged in the network, almost documents are distributed surround Actor 2 and 5, but not change too much on the positions of actors. Degree centrality changes a lot especially for the 7 core actors. Actor 2 and 5 has the smallest size whilst the other 5 actors has a lot more connections. The strength of social tie in this network, edges between Actor 2 and documents, and edges between Actor 5 and documents are stronger than all the other edges.

Comparing Figures 1 and 3, impressively, when two network maps are generated automatically from Gephi, two networks are found similar in the positions of actors, but different in connectivity of actors. This similarity suggests that both analyses, either of the actor interaction network and the document-actor interaction network, will provide similar results. From the Actor interaction network, it shows that this is a quite stable information exchange network, with small amount of actors participated. Degree centrality and strength of social tie of Actor 2 and actor 5 (see Figure 2) are far more distinctive than other actors, which means they are processing the largest portion of information within this network. This two actors themselves have no relationships but highly connected by 5 other core actors with strong ties indicate they are working stable as an established team and Actor 10 works mainly for approval. But when engages documents as nodes positioned in the network, the changes on degree centrality within the core network shows senders (Actor 2 and 5) are processing more amount of information than recipients, but the recipient actors in the core are accessing to more documents than those two main senders.

5. DISCUSSION AND CONCLUSIONS

This study contributes to work on social network analysis of interactions in digitally-enabled construction projects by using data collected directly from the digital collaboration system. Respected to the visual analytics studies in construction (Russell et al. 2009), the implementation of SNA will extend the visualization capability of digital project data. The use of digital dataset as data source expends the data sources in the construction network research (Loosemore 1998, Chinowsky et al. 2008, Pryke 2012).

The data of this paper reflect all interactions within the web-based collaboration system, but it is challenged in considering and balancing the collaboration system facilitated interactions and other interactions outside the system. And if the digital collaboration system facilitated interactions are considered as standardised and established formal information exchanging processes, some of interactions in the 'Notice, Permit & Permission' documents are retrieved for emerging issues. This is challenged in how to depict the informal collaborations associated with the formal process.

Many researchers combined qualitative analysis with social network analysis to interpreted these network research constructs with contextual meanings (Loosemore 1998, Pryke 2004, Larsen 2011, Iorio et al. 2012). Situated in this particular research, qualitative analysis can be conducted in two ways: one is to work on the content of information exchanged in the collaboration system, and another one is obtaining more qualitative data such as interviews for more in-depth understandings, so there is an analytical challenge emerged to develop an analytical framework to the technology embedded mega data (information exchange network data) and the contextual understandings.

6. FURTHER RESEARCH

The preliminary findings are grounded on the data collected from the database of a web-based collaboration system. As the data obtained for the purpose of network analyses, it limits on the existing study. Some of the content is missing, however it does not affect to develop a more detailed procedure for data analysis – refining techniques for obtaining data from the digital collaboration system. Preliminary findings specify three types of documents in this collaboration system. So, the network analysis are aimed to provide stipulated understandings on how different types of documents processed in the digital collaboration system, which contribute to the knowledge of approval processes of digitally-enabled construction projects.

Further information will be obtained to analyse the actual interactions around 'Contract', 'Drawings and 'Notice, Permit & Permission' documents to continue steps c-f in research design. In steps c and d, each type of documents will be analysed independently regarding to their stipulated work traditions.

- ‘Contract’ type of documents is selected because it is tightly coupled with approval process. Actors network does not change contrast to the documents involved interaction network, as it is limited with the missing contextual data, no further interpretations concludes on the assumption about whether this network relationship in digital collaboration system, relates to the actual contractual relationships (Dewulf and Kadefors 2012, Pryke 2012) or reflects on the actual contracting process (Hoezen et al. 2011).
- The second type, ‘Drawing’ is almost 5 times of ‘Contract’ in total amount and are normally requires higher collaborations to promote performance in getting the finalized documents approved. This information exchanging network study on design development and approval processes may contribute to digitally-enabled collaborations studies in design phase from building projects (Pryke 2012) to infrastructure construction projects.
- In ‘Notice, Permit & Permission’ documents, some are emerging documents delivering unexpected issues. In some extent, these documents represent the informal collaborations through the formal processing system. Therefore, it may expected to specify an expanded understanding and implementation of formal collaboration system in facilitating informal collaborations (Gu and Jarvenpaa 2011).

These three types of documents domains the most typical works in construction projects, so the independent analyses will used to narrative a story of documents approval processes in a digital collaboration system. This paper has reported preliminary work on steps a-d of our research method (as reported above), we are now conducting more detailed analyses of the whole dataset and seeking contextual information (steps e-f) to inform the interpretation of information from the digital collaboration system.

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