HEALTHY BUILDINGS: INNOVATION, DESIGN & TECHNOLOGY

ICAT 2016

ANTONIO GALIANO GARRIGÓS
TAHAR KOUIDER

CONFERENCE PROCEEDINGS OF THE 6TH INTERNATIONAL CONGRESS OF ARCHITECTURAL TECHNOLOGY
UNIVERSITY OF ALICANTE 12-14 MAY 2016

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IMPLEMENTATION FEASIBILITY OF A DIGITAL NERVOUS SYSTEM FOR THE CONSTRUCTION INDUSTRY

For Efficient and Effective Information Management across the Project Lifecycle

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Abstract. The construction industry has long been considered as highly fragmented and non-collaborative industry. This fragmentation sprouted from complex and unstructured traditional coordination processes and information exchanges amongst all parties involved in a construction project. This nature coupled with risk and uncertainty has pushed clients and their supply chain to search for new ways of improving their business process to deliver better quality and high performing product. This research will closely investigate the need to implement a Digital Nervous System (DNS), analogous to a biological nervous system, on the flow and management of digital information across the project lifecycle. This will be through direct examination of the key processes and information produced in a construction project and how a DNS can provide a well-integrated flow of digital information throughout the project lifecycle. This research will also investigate how a DNS can create a tight digital feedback loop that enables the organisation to sense, react and adapt to changing project conditions. A Digital Nervous System is a digital infrastructure that provides a well-integrated flow of digital information to the right part of the organisation at the right time. It provides the organisation with the relevant and up-to-date information it needs, for critical project issues, to aid in near real-time decision-making. Previous literature

review and survey questionnaires were used in this research to collect and analyse data about information management problems of the industry – e.g. disruption and discontinuity of digital information flow due to interoperability issues, disintegration/fragmentation of the adopted digital solutions and paper-based transactions. Results analysis revealed efficient and effective information management requires the creation and implementation of a DNS.
Keywords. *Digital Nervous System, Information Management, Construction Project Lifecycle, Building Information Modelling, Enterprise Resource Planning, Document Management System.*

1. Introduction

The construction industry has long been considered highly fragmented and non-collaborative (Sommerville & Craig, 2006; Egan, 1998; Latham, 1994). This fragmentation is a result of unstructured coordination processes and information exchanges amongst all disciplines involved in a construction project (Figure 1). In addition to risk and uncertainty this has necessitated looking for new ways of improving business processes to deliver better quality and high performing product. Egan (1998) and Latham (1994) advocated that in order for the construction industry to improve its performance and overall quality, a change in culture and the adoption of collaborative working practices should be implemented. They further noted that this collaborative culture should be supported by efficient flow of information between project teams and across organisational boundaries.

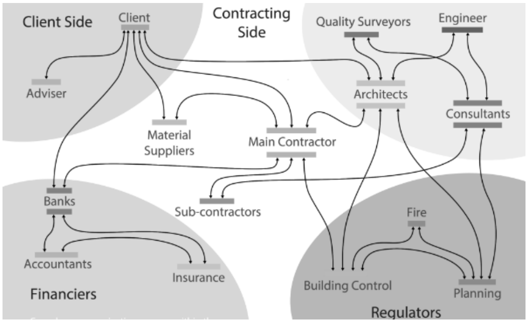

Figure 1. Complex communication processes within the construction industry (adopted from Sommerville & Craig, 2006)

Therefore, critical to running any construction project is the continuous flow of information throughout the project lifecycle – from design to construction and handover phases. This means that the management of the construction project, in particular management of information, needs to be structured in a logical order using a system or a combination of systems that ensure the project participants have instantaneous access to all project information. Thus, clients and their supply chain have implemented computerised solutions, to digitise existing manual processes and to exchange and receive information digitally. However, since the information produced by each project stakeholder is unique to their own use and purpose, they have resorted to the use of various types of software applications to satisfy their own contractual needs – many software disintegrated and standalone. This disintegration resulted in the production of different file formats concealed within each organisation, exacerbating information flow from one organisation to the other, causing disruption and discontinuity of information flow across the project lifecycle (Arnorsson, 2014).

Other industries such as healthcare previously faced the same dilemma when it comes to the flow and management of information (Patrick et al., 2005; Gates, 1999). To overcome this problem, the healthcare industry implemented a Digital Nervous System (DNS). Its benefits included sharing, visibility, and re-use of data amongst disparate healthcare applications and devices (Perficient, 2015; Gates, 1999) to be discussed below. The scope of this paper is limited to ascertaining the need to implement a digital nervous system in the construction industry by directly investigating the relationship between paper-based communication and the adoption of inefficient and disintegrated digital solutions, and the disruption and discontinuity of the flow of information across the project lifecycle. The subsequent sections will discuss currently adopted ICT solutions to manage construction information, the gap being explored, the method of data collection, and the results of the analysis to support the investigation.

2. Background

During the 1970's business processes were not yet digitised, thus activities involving exchanges of information were performed physically through paper-based transactions, a practice called file management (Knox, 2013). With the proliferation of information and communications technology (ICT), the majority of created, stored and shared information became digital, thus the lifecycle management of digital information was termed information management (Galliers & Leidner, 2003). According to the Association of Information and Image Management (2015), information management is: "the collection and management of information from one or more sources and the distribution of that information to one or more audiences. Management means the organisation and control over the structure, processing and delivery of information."

Critical to the management of information is the continuous flow of information from one source to the other. Phelps (2012) advocated that information flow requires four (4) components: "a starting point (source), an ending point (receiver), a path (interaction) and a driving force (mutual relevance)". He further noted that in the construction industry, there are two types of entities that can serve as sources or receiver of information, these are: "1) People and 2) Boundary Objects (e.g. drawings, reports, building information models, request for information and other documents that enable communication between groups of people)." Phelps (2012) added that during these interactions, some information is rejected or ignored and becomes waste (Figure 2) unless shared again by different circumstances. However, as the construction project progresses the amount of information grows at an exponential rate – thus making it a challenge to retrieve previously ignored or rejected information. Currently, interactions such as creation, sharing, storage and retrieval of information in the construction industry are largely supported by the use of ICT, and understanding these interactions is critical to improving the flow of information and the overall quality of the project.

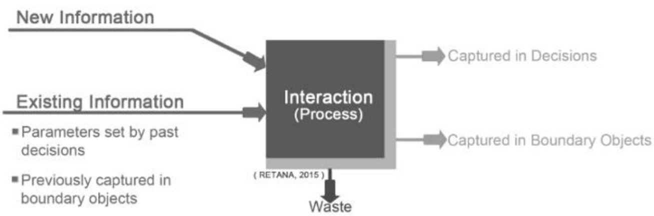

Figure 2. Fundamental Structure of the Flow of Information in a Construction Project (adopted from Phelps, 2012)

Construction project lifecycle begins with organisational strategic planning and formulation of a client brief with a list of client's needs and requirements (Sears et al., 2015). This is followed by design, construction and handover of the facility. The information that is managed during the whole design process typically includes contract agreement, project brief, site information, cost plan, scope of services, project programme, project quality plan, BIM execution plan, final design drawings, tender and contract specification. While the information that is managed during construction and handover phase typically includes contract drawing & specification, master programme, project handbook, method statement, product data, shop drawings, non-compliances report, project execution plan, field observation report, operations & maintenance manual, among others. (Sears et al., 2015)

McGraw Hill Construction (2013) and Sekou (2012) identified Enterprise Resource Planning (ERP) Systems, Electronic Document Management Systems (EDMS) and Building Information Modelling (BIM) Applications as the most commonly adopted proprietary software applications in the construction industry that manage information at administrative, operational level and perform activities e.g. planning, scheduling, drawing documentation, procurement, and visualisation. Most of this software is standalone proprietary applications, thus may cause several problems.

For instance, ERP systems' capabilities are only limited to business processes e.g. finances, resource, supply chain, and project management, marketing and sales, with no evidence for possibility to integrate with other specialised business processes such as design analysis, field information gathering and drawing documentations through the use of building information modelling applications (BLM, 2013). In fact, Arnorsson (2014) further cited that due to these limitations, "ERP has only been used for administrative purposes in construction." EDMS on the other hand requires IT-extensive effort to integrate other business systems such as ERP systems, thus unfavourable to smaller organisations (RICS, 2014). Moreover, storage flexibility is also an issue with current EMDS applications. Although it seems that EDMS provides unlimited storage capability to any projects, it is still not designed to accommodate large data volumes thus individual project data is still isolated and stored independently and requires enormous amounts of time, cost and effort to integrate all historical project data into a single unified location (Docfinity, 2015; Aconex, 2015). Regarding BIM, buildingSmart Australasia (2015) emphasised that the current shortfall of BIM in the management of construction information was due to its "disintegrated technology approaches; thus urgently requires the adoption of an integrated technology solution." They further noted that the vast amount of information, created or captured in relation to the physical asset, can only be accessed and managed through federated information models thus requiring a 'file-level' exchange of information.

The same problem was previously faced by the healthcare industry in managing information (Patrick et al., 2005). Success of hospital activities is determined by how well the relevant stakeholders can monitor and control all types of hospital information. In most cases, the healthcare providers are burdened with the retrieval of patients' medical data records that are concealed within different divisions, lack of storage of healthcare electronic information resulting in the continuous use of paper-based transactions, interoperability issues due to the use of disintegrated electronic medical record (EMR) applications, as well as the implementation costs of automating those processes (Word Health Organisation, 2012; Sandmark, 2008). Another challenge faced relates to the protection of patient privacy. (Berkowitz & McCarthy 2012, Word Health Organisation, 2012) To address those challenges, the healthcare industry has implemented the use of a digital nervous system (DNS). This refers to a technological infrastructure that offers a flow of digital information that is well integrated, and ensures that it flows to the right part of the organisation at the correct time (Dumbill, 2012; Gates, 1999). The digital nervous system is similar to the biological nervous system (specifically the autonomic nervous system). First, the two systems consist of inputs that are multisensory in nature. Second, they both incorporate the concept of intelligence sifting in their operations. Moreover, they are able to adapt to the significant changes in the environment as well as reacting hastily to various situations. In addition, as Gates (1999) stated, "both are capable of learning from experiences". The premise of implementing DNS is to eliminate the use of paper-based transactions and to integrate existing digital solutions to provide a single unified source of digital information. As Gates (1999) stated, "DNS simplifies the implementation process of a hospital's Electronic Medical Record (EMR)". A DNS might thus enhance construction-related operations in a similar way as it is capable of collecting transaction information in near real-time.

3. Research Rationale and Description

Despite the widespread adoption and advances in digital technology, the construction industry is still experiencing severe problems related to low profitability, poor quality of resulting product, high wastage and fragmentation (Aapaoja & Haapasalo, 2014). Most of these problems are associated with information management problems (Vo-Tran, 2014) e.g. disruption of the flow of information across the project lifecycle due to heavy reliance on paper-based communication, interoperability issues, inefficient interfaces between digital solutions to access digital information, adoption of inefficient transaction-specific disintegrated digital solutions and the inability to capture and analyse relevant information for future use. Therefore the aim of this research is to examine the relationship between the fragmented approach to information management (independent variable) and the disruption of the flow of information across the project lifecycle (dependent variable) due to the above factors. Correlation or association is tested using Chi squared (X2) test, Pearson's Correlation Coefficient (R) and calculating p-values. A strong correlation between the variables and p-values <0.05 would invalidate the null hypotheses detailed below, thus suggest the need to implement a Digital Nervous System for the construction industry –as proven/refuted in the discussion and analysis of results section. This section also explains the qualitative and quantitative methods and tools used, interviews and survey questionnaire, sampling and variables considered to support the investigation. The null hypotheses tested in this study are:

Null Hypothesis 1: No relationship exists between the reliance on paper-based communication and the disruption and discontinuity of the flow of information across the project lifecycle.

Null Hypothesis 2: No relationship exists between the adoption of inefficient transaction-specific digital solutions and the disruption and discontinuity of the flow of information across the project lifecycle.

Null Hypothesis 3: No relationship exists between the adoption of disintegrated and fragmented digital solutions and the disruption and discontinuity of the flow of information across the project lifecycle.

The first part of the data collection process was accomplished through issuance of an online survey questionnaire. The participants were from diverse disciplines in the construction industry from multi-sized companies; architecture, civil, structural, services engineering, quantity surveying, rail, urban design & landscape, contractors, manufacturers, consultants, project managers, and fabricators. Total respondents of this survey were 143. Stage two of the data collection process was interviews and these were conducted both face-to-face and virtually. Interviews duration was 60 - 90 minutes. The quality of data collected was reliant on understanding as well as information of the interviewees. Interviewees represented 3 sizes of organisations i.e. 1-50, 101-200 and more than 200 employees, similar to the survey questionnaire to maintain consistency and reliability of the data collected. A total of 12 interviews were conducted, 10 from the construction industry and 2 IT professionals who are experts in information management. At the end of each interview, a summary transcript was shared with each interviewee to confirm the information captured. All interviews were semi-structured to emphasise on the interviewees' opinions and views giving suppleness to deliberate parts that were not formerly measured.

4. Analysis and Discussion of Results

When respondents were asked to rate from 1 to 5 how disrupted the flow of information was, a total of **67%** expressed that a higher degree of disruption (level 4 & 5) was experienced within their organisations (Figure

3). The extent of disruption was dependent on type of organisation e.g. almost **80**% of Architects and **86%** of Interior Designers indicated higher degrees of disruption, providing evidence for disruption of the flow of information as perceived by the construction professionals.

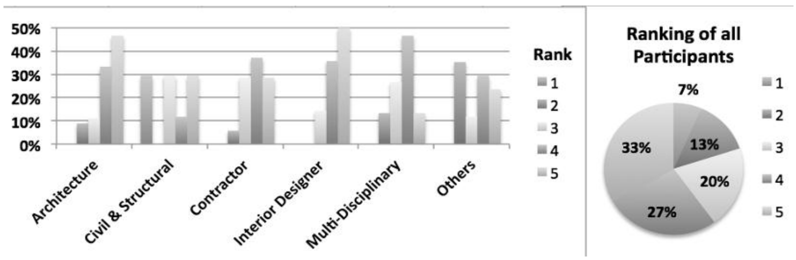

Figure 3. Level of information Disruption vs. Type of Organisation

To further test this assumption, Chi-squared Test of Independence was performed between the perception of the level of disruption and the type of organisation. A p-value of **0.001** was obtained hence providing evidence that there might be a dependence between the perception of the level of information disruption and **type of organisation**. Hence further analysis was performed to test whether the level of information disruption is dependent on the **size of organisation**. As demonstrated in Figure 4, the information disruption was perceived more pronounced for large organisations composed of more than 100 members. This could indicate that as information is passed on to different (inefficient) channels through different departments, its fidelity changes from its original form. A p-value of **0.022** also indicates a degree of dependence between levels of disruption and size of organisation.

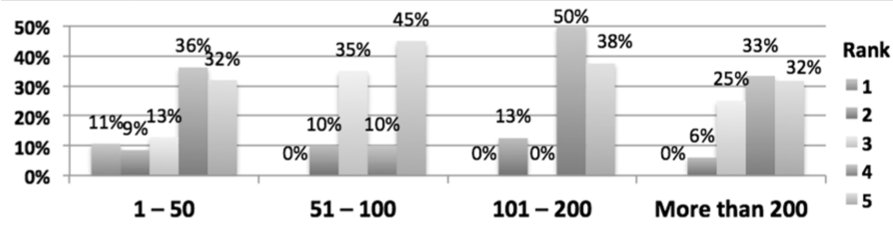

Figure 4. Level of information Disruption vs. Size of Organisation

Since evidence above was provided of disruption and discontinuity of the flow of information experienced by the construction professionals regardless of type and size of organisation, the following analysis was performed to test Null Hypothesis 1, whether the disruption of the flow of information is independent of paper-based communication (as an indication of fragmented approach to information management). As figure 5 demonstrates, the higher the mode of communication/production/update depends on paper format, the higher the information disruption. Conversely, lesser extent of information disruption is felt when communication is done digitally.

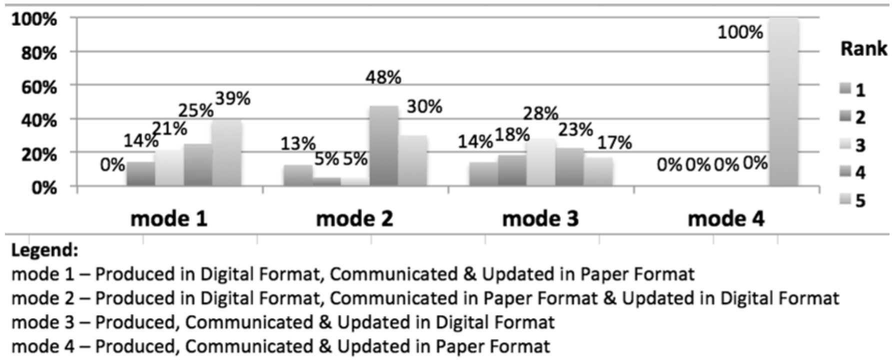

Figure 5. Level of information Disruption vs. Mode of Information Communication

Using Chi-squared test of independence, p-value of **0.001** rejects the null hypothesis thus indicating that the extent of information disruption could be dependent on the type of communication used, exasperated by paper format.

Moreover, the model calculated a coefficient of variation of **15.1%**, i.e. 15% of the variations of disruption can be accounted to the type of communication used. The model also suggests that there is still 85% margin that can be accounted to other disruption factors such as personal, environmental, and/or adoption of inefficient and disintegrated digital solutions. Hence the subsequent analyses test whether the extent of information disruption is independent of the use of inefficient transaction-specific digital solutions (Null Hypothesis 2); i.e. methods used for **transferring**, **receiving**, **storing, capturing** and **recording** project information, work progress and defects data, issuance, tracking and management of RFIs. Percentage usage of different methods in organisations is shown in figure 6 and 7 below from data collection.

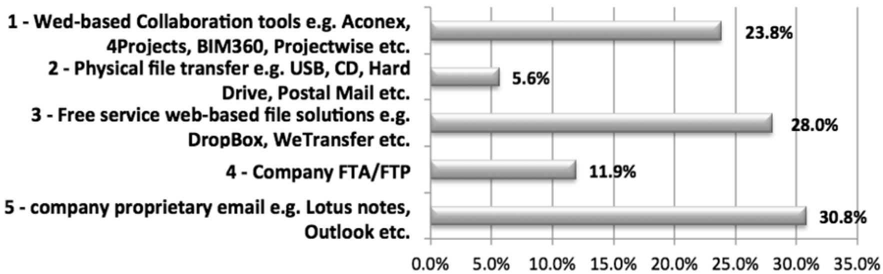

Figure 6. Methods used for transferring &receiving project information

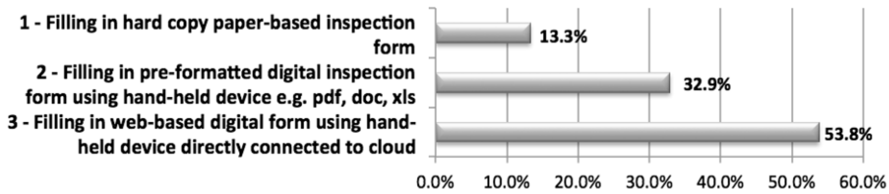

Figure 7. Methods used for capturing & recording of work progress and defects data

On calculating Pearson's Correlation Coefficient (R) results showed a negative association between extent of disruption of information (dependent variable) and the method used for transferring and receiving project information (independent variable) with **R= -0.219**. This can indicate that as organisation tend to use web-based collaboration tool, the lesser the extent of disruption will be experienced. The p-value of **0.011** indicates that the results are statistically significant; thus the null hypothesis 2 was rejected.

On a similar argument, results demonstrate a low negative association between the extent of information disruption (dependent variable) and extent of 1) method used for storing project information i.e. company server and web-based cloud storage (independent variable), and 2) method used for capturing and recording of work progress and defects data on site; with R= **-0.164** and **-0.204** respectively. This might indicate that as organisations aim for centralised web-based cloud storage, and web-based data management tools for capturing and recording work progress and defects on site the extent of disruption decreases. The p-values of **0.025** and **0.007** respectively indicate the rejection of the null hypothesis 2.

Other identified factors, e.g. adoption of disintegrated digital solutions, were analysed to test for no association with disruption and discontinuity of the flow of information (Null Hypothesis 3). Also Chi-squared test of independence was used to test if the extent of information disruption (dependent variable) is associated to the adoption of disintegrated digital solutions (independent variable) i.e. use of Electronic Document Management System (EDMS), Enterprise Resource Planning (ERP), and Application Programming Interface (API). Figure 8 and 9 suggest that **60-80%** of the professionals who both do and do not use EDMS, ERP, and API to manage their corporate as well as project information experience a high degree of information disruption (scales 4&5) within their organisations (the figures being heightened with standalone non-integrated EDMS and ERP systems). This can indicate that the extent of information disruption might be associated with usage of these systems (EDMS, ERP and API), hence necessitating a more efficient well-integrated system for flow of digital information throughout the project lifecycle, e.g. using a Digital Nervous System (DNS) to create a tight digital feedback loop that enables the organisation to sense, react and adapt to changing project conditions in near real-time, allowing near real-time decision-making.

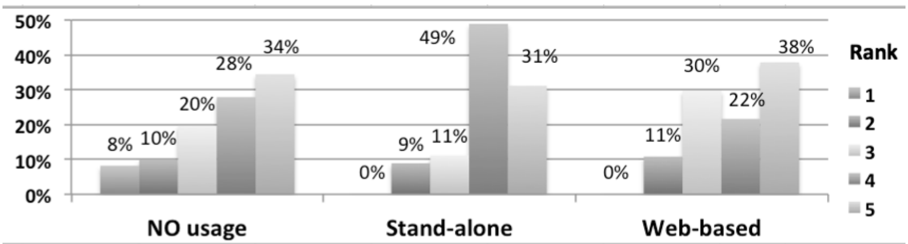

Figure 8. Level of information Disruption vs. EDMS Usage

Furthermore, p-values of **0.041** for **EDMS, 0.001** for **ERP** and **0.004** for **API** provide evidence against the null hypothesis. Therefore the null hypothesis 3 was rejected that there is no relationship between the adoption of disintegrated and fragmented digital solutions and the disruption and discontinuity of the flow of information across the project lifecycle.

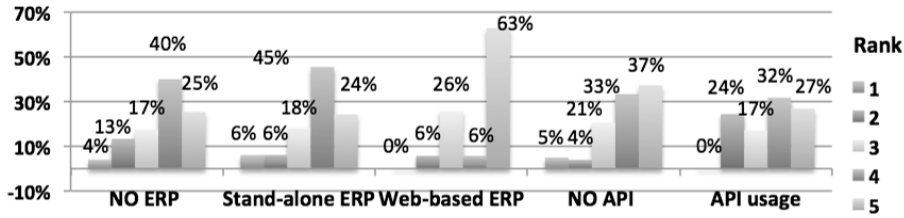

Figure 9. Level of information Disruption vs. ERP and API Usage

5. Conclusion

The goal of this research was to examine the need to implement a DNS by directly investigating the relationship between the disruption of the flow of information across the project lifecycle and the fragmented approach to information management. This research demonstrated that the disruption and discontinuity of the flow of information was prevalent across organisations regardless of the type and size of the organisation. Furthermore, it has also been shown that the continuous used of paper-based communication and the adoption of inefficient and disintegrated digital solutions has negatively influenced the flow of information across the project lifecycle. Thus, there is an urgent need to consider creating and implementing a DNS for the construction industry. Future research will be conducted to determine the appropriate composition of a DNS Framework and how it can provide a well-integrated flow of digital information across organisations, which can be achieved through focus groups from the construction and IT industry. Furthermore, the DNS framework and its physical infrastructure shall be tested through a series of experimental studies to ascertain its effectiveness and efficiency in managing information for the construction industry.

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