MANAGING THE COMPLEXITY OF INFORMATION FLOW FOR CONSTRUCTION SMALL AND MEDIUM-SIZED ENTERPRISES (CSMES) USING SYSTEM DYNAMICS AND COLLABORATIVE TECHNOLOGIES

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With the increase in e-commerce and the digitisation of design data and information, the construction sector has become reliant upon IT infrastructure and systems. The design and production process is more complex, more interconnected, and reliant upon greater information mobility, with seamless exchange of data and information in real time. Construction small and medium-sized enterprises (CSMEs), in particular, the speciality contractors, can effectively utilise cost-effective collaboration-enabling technologies, such as cloud computing, to help in the effective transfer of information and data to improve productivity. The system dynamics (SD) approach offers a perspective and tools to enable a better understanding of the dynamics of complex systems. This research focuses upon system dynamics methodology as a modelling and analysis tool in order to understand and identify the key drivers in the absorption of cloud computing for CSMEs. The aim of this paper is to determine how the use of system dynamics (SD) can improve the management of information flow through collaborative technologies leading to improved productivity. The data supporting the use of system dynamics was obtained through a pilot study consisting of questionnaires and interviews from five CSMEs in the UK house-building sector.

Keywords: construction small and medium-sized enterprises (CSMEs), cloud computing, information mobility, productivity, system dynamics.

INTRODUCTION

The construction sector is fragmented, project based (and therefore mobile/temporary) with many types of information needed by so many different stakeholders (Betts, 1999), including clients, regulatory authorities, consultants, contractors and the supply chain.

Information flow serves as the backbone for all successful projects across the construction sector. Construction small and medium-sized enterprises (CSMEs) are an important part of the UK construction sector to absorb collaboration-enabling technologies such as cloud computing that has the ability to provide a platform for cloud collaboration tools, facilitating transfer of information and data in digital format using digital devices such as smart phones, tablets and laptops on construction sites. The aim is to provide accessibility to information to improve productivity. Productivity is defined as a ratio of a measure of output to a measure of some, or all of the resources, used to produce this output (Grimes, 2007). Productivity improvement

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is an increase in the ratio of produced goods or services in relation to resources utilised (Pekuri *et al*., 2011).

The research investigates the use of system dynamics (SD) methodology as a modelling and analysis tool in order to identify the key drivers in the absorption of cloud computing in CSMEs. The aim is to determine how system dynamics (SD) can improve management of information flow leading to improved productivity, using cloud computing technology and cloud collaboration tools for CSMEs. The focus is at the production stage on the construction site. System dynamics is a tool that can be used to address the complexity in the management of information flow on construction sites. Consideration is given to information flow through the value chain from the design team to the speciality contractor, focusing upon the speciality contractor. Most research has been concerned with information flow between the design team and the main contractor, whereas with specialisation and the out-sourcing of work packages, the role of specialist contractors is increasingly important in the information flow process.

INFORMATION MOBILITY

Information and data moves from the design offices through to the construction site, it needs to be accessed by construction personnel to carry out relevant construction activities. The site is concerned with converting the design into production processes, which involve a plethora of different skills and trades. Whilst the overall process is interdependent, each of the specialty contractors is focussed on their work package. Each specialist requires different information to fulfil their work package, with the overall goal of the main contractor to co-ordinate such information and data. The specialty contractors care about safety, delivery on time, within budget, to ensure the work package is profitable. Computer Aided Design (CAD) and Building Information Modelling (BIM) has meant that design is more dynamic, with faster reaction times on projects. The speciality contractor must deal with change orders, materials delivery, and resource availability. However, there is generally a paucity of information and data on construction sites (Chen and Kamara, 2008). The information and data is frequently of variable degrees of intensity and diversity with variability in accuracy. The research has focussed on project information which includes models, drawings, emails, mark-ups, submittals, transmittals, images, contracts, specifications, change orders and other documentation that are created in the course of designing, building and operating facilities.

On-time and accurate information provided during the production stage reduces errors, rework and delays reducing the likelihood of contractual claims, disputes, and the requirement for change orders. Timely information and communication also contributes towards improved health and safety on construction sites (HSE, 2002). It helps in completing projects on time, with reduced costs and improved quality (Titus and Bröchner, 2005). Moreover, information in real time about external factors that influence production, such as inclement weather, or a significant design change being proposed by the client and design team, can help to forward plan activities, so that to minimise disruption to production.

There is a need to manage the complexity of information flow on construction sites from the perspective of all the stakeholders in the production and delivery chain. The characteristic of this research is that it takes a bottom-up approach, viewing production from the site team. Collaboration-enabling technologies have the ability to provide a platform for software collaboration tools that can improve information mobility and the information and data transfer. Information mobility is about ensuring seamless exchange of information in the right version, in the appropriate format and with the required level of reliability, accessed by the right people, at the right time. The users are as important to information mobility as the technology; mobility will depend on the user's motivation, whether they can afford to use it, and if they have the ability to do so (Peters, 2004). Collaboration between all organisations involved in a project has become a fundamental requirement in construction. Effective collaboration strategies provide document access across any endpoint, deepen connections with partners and increase productivity.

CONSTRUCTION SMALL AND MEDIUM-SIZED ENTERPRISES

Figure 1 shows that small and medium-sized enterprises (SMEs) in the UK account for 99.8 % of all businesses, 60 % of employment and 47 % of turnover. Construction SMEs are 18.12 % of all SME businesses, with 85 % of employment and 73 % of turnover in the UK construction sector (BIS, 2014).

Figure 1: UK SMEs' Statistics (BIS, 2014)

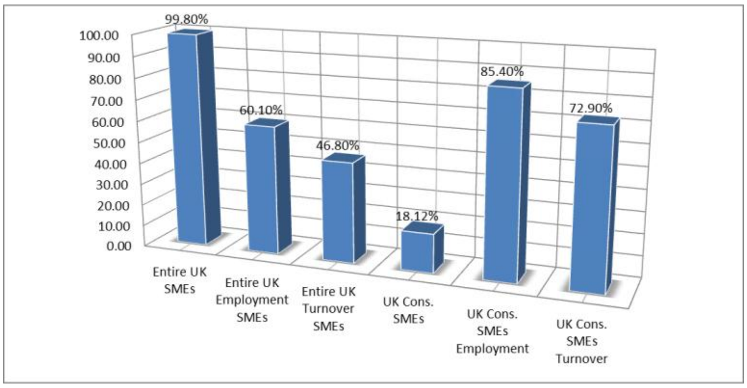


Table 1 shows the European Commission (2005) definition of an SME according to number of employees and annual turnover of a business.

Table 1 Definition of SME's (European Commission, 2005)

Enterprise category	Headcount: Annual Work Unit (AWU)	Annual turnover	or	Annual balance sheet total
Medium-sized	< 250	≤ € 50 m		≤ € 43 m
Small	< 50	≤ € 10 m		≤ € 10 m
Micro	< 10	≤ € 2 m		≤ € 2 m

In a small firm, the productive activity represents the heart of the organisation (Di Tommaso and Dubbini, 2000). This led this research to focus on the firm's productive capacity and capability on the construction site. Sexton and Barret (2003a) identified four unique challenges and characteristics of small construction firms:

1. limited staff capacity as well as capability restricting their ability to undertake necessary research and development (R&D);
2. limited time and resources for external interaction that results in restricted flow and amount of information;
3. mostly dominated by single owner or small team who may use inappropriate strategies and skills; and

   facing difficulty in maintaining an adequate cash flow that results in limited scope for capital or on-going investment in innovation activity.

To the list can be added two further factors, firstly, the lack of systems and procedures with feedback loops providing real-time information on performance and productivity. Secondly, lack of formal organisational structures in CSMEs, which means the lack of systems integration across the business. CSMEs work on both small and large projects as main contractors, sub-contractors, or specialty contractors. Large projects involving work packages that are outsourced to specialty contractors. Large organisations outsource to reduce overheads (Langford and Male, 1992), leading to an increase in number of specialist contractors. Such an increase requires more information and document management with increased integration across all the stakeholders, including consultants and contractors. This can be achieved through increased information mobility especially in the house-building sector that involves a lot of specialist contractors working on a single generic product.

CLOUD COMPUTING AND THE CONSTRUCTION SMES

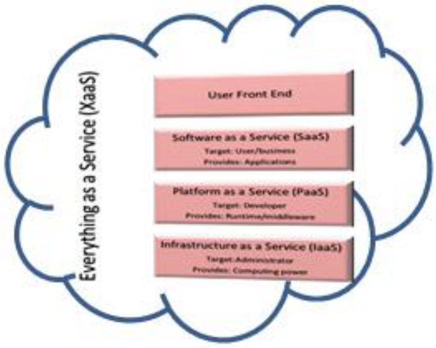
The US National Institute of Standards and Technology (NIST) define cloud computing as:

"a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g. networks, servers, storage, applications and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction."

(Mell and Grance, 2011, p. 2)

Cloud computing is a general term for anything that includes providing hosted services over the internet (Beach *et al*., 2013). Everything in cloud computing is treated as a service i.e. (XaaS) e.g. SaaS (Software as a Service), PaaS (Platform as a Service) and IaaS (Infrastructure as a Service). These services define a layered system structure for cloud computing as shown in Figure 2. At the Infrastructure layer, processing, storage, networks, and other fundamental computing resources are defined as standardized services over the network. Cloud providers' clients can deploy and run operating systems and software for their underlying infrastructure. The middle layer, i.e. PaaS provides abstractions and services for developing, testing, deploying, hosting, and maintaining applications in the integrated development environment. The application layer provides a complete application set of SaaS. The user interface layer at the top enables seamless interaction with all the underlying XaaS layers (Pallis, 2010).

Figure 2: Cloud Computing: a general layered architecture (Pallis, 2010, p. 71)



Cloud computing consists of four deployment models: firstly, private cloud, which is a cloud infrastructure meant for exclusive use by a single organisation. Secondly, the community cloud; a cloud infrastructure meant for exclusive use by specific community of consumers from organisations that have shared concerns. Thirdly, the public cloud which is a cloud infrastructure meant for open use by the general public, and fourthly the hybrid cloud consisting of two or more cloud infrastructures (private, community or public cloud) that remain unique entities, but are bound together (Mell and Grance, 2011).

Information Technology (IT) has always been considered as the most vulnerable aspect for technology absorption, despite being extremely important to the construction sector. Construction SMEs are an integral and important part of the UK construction sector. The absorption of IT technologies is low mainly due to the lack of human and financial resources required to use and maintain IT investment (Cheng and Kumar, 2012). There is a general lack of awareness and indifferent attitude towards new information technology displayed by construction SMEs. Cloud computing is an emerging technology that is both innovative and cost-effective. It does not require huge investments in money and time; it can make use of the existing IT infrastructure and get access to computing resources that can be configured according to the requirements of the organisation, with payment based on pay-as-you-go. The main drivers of cloud computing include economics, simplification, and convenience, in the manner that computing related services are delivered (Erdogmus, 2009).

CSMEs can adopt the Hybrid-SaaS model, with a combination of public and private cloud. The Hybrid-SaaS model provides opportunities to store data on an 'on - premise' server that is managed by the organisation, while providing opportunities to use the cloud (Hoehne, 2012). The Hybrid-SaaS model can facilitate both the specialist contractor, and the main contractor to regulate accessibility to information, allowing only the relevant project information to be accessible to all the concerned parties and the construction site personnel. There are many cloud collaboration tools, including Microsoft One Drive, Google Drive, iCloud Drive, Huddle, Evernote and Dropbox. Information can be accessed through cloud collaboration tools using digital devices such as smart phones, tablets and laptops on construction sites. Digitisation has meant the availability of more information, ultimately leading to greater complexity and interconnectivity. System dynamics is a way of managing complexity.

SYSTEM DYNAMICS

System Dynamics (SD) was developed by Forrester (1961) to reflect the view that the dynamics of industrial systems result from underlying the structure of flows, delays, information and feedback (Dangerfield *et al.*, 2010). Mathematical models of the relations between system components are constructed and computer simulation can help to optimise the system. System dynamics (SD) offers a perspective and tools that enable a better understanding of the dynamics of complex systems.

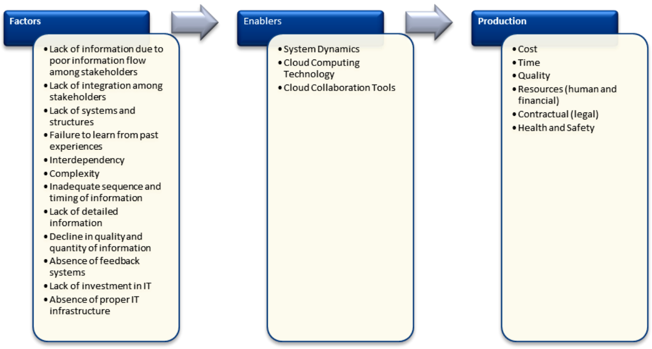
System dynamics is interdisciplinary and in order to study the behaviour of complex systems, it is grounded in the theory of non-linear dynamics and feedback control developed in mathematics, physics, and engineering. These tools are applied to the behaviour of human, as well as technical systems. It also draws on cognitive and social psychology, organization theory, economics, and other social sciences to solve important real world problems (Sterman, 2000). System dynamics approach has the ability to create ‘micro worlds’ that present real world issues in a manner that are simple, practical, structured, and comprehensible. The strength is in the ability to break down complex systems into comprehendible sub-systems. System dynamics addresses complexity and process relationships based on non-linear feedback systems.

It can help improve information flow, through collaborative technologies leading to improved productivity.

MAPPING CONSTRUCTION PROCESS

A pilot study was conducted using questionnaires and face to face interviews was used to investigate the challenges faced by the CSMEs in information management on projects, and the impact on various parameters relevant to CSMEs during the site production phase of projects. The pilot study considered how system dynamics can help to improve information flow through collaborative technologies. The findings have been categorised as 'Factors', 'Enablers' and 'Production' illustrated in figure 3 and will feed the main data collection.

Figure 3: Mapping the Construction Process



The 'Factors' are the issues faced by CSMEs; the respondents described the increasingly complex nature of the construction sector. The 'Production' category lists the elements directly affected by the 'Factors' affecting both the construction project, and the specialist contractors. The 'Enablers' lists important tools that have the ability to address the issues in the 'Factors' category. It is focussed on the use of system dynamics to manage the complexity of information flow using collaborative technologies leading to productivity improvement. The 'Factors' act as an input to 'Enablers'. The 'Enablers' help address the issues in the 'Factors' category which in turn helps to address the elements listed in the 'Production' category.

A major failing in many systems is the influence of complexity and feedback systems. The construction sector is particularly poor in using robust and reliable feedback systems. Therefore, system dynamics was used as a tool to address complexity and process relationships, based on non-linear feedback. A model was developed to improve the management of information flow, using cloud computing technology and cloud collaboration tools for CSMEs on construction sites. The model is useful for the specialist contractors, it provides a system and procedures with feedback loops that has the potential to provide and capture real-time information on performance and productivity.

SYSTEM DYNAMICS MODEL

SD modelling tools consist of causal loop diagrams (CLDs), and stock and flow diagram (SFDs). CLDs are an important tool that represents the feedback structure of systems. It consists of variables that are connected by arrows representing causal influences among the variables. These can be either negative (balancing) feedback or positive feedback (reinforcing) loops. Stocks are accumulations and depict the state of the system that generates information upon which decisions and actions are based (Sterman, 2000).

Figure 4: Causal Loop Diagram (CLD)

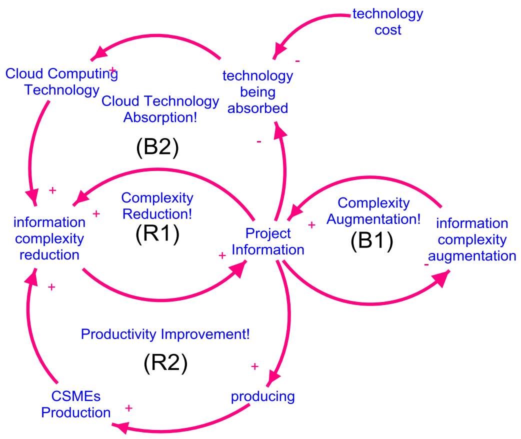


Figure 4 illustrates a causal loop diagram (CLD). The CLD is based upon the findings of the pilot study and consists of four important loops which are described as:

Reinforcing Loop R1: Complexity Reduction

In the causal loop diagram, the reinforcing loop (R1) shows that an increase in 'Project Information ' leads to an increase in 'information complexity reduction' and an increase in 'information complexity reduction' leads to a corresponding increase in 'Project Information' thereby improving information flow on construction site.

Balancing Loop B1: Complexity Augmentation

The balancing loop (B1) shows that a decrease in 'Project Information' leads to an increase in 'information complexity augmentation' which leads to a decrease in 'Project Information' on construction site affecting productivity.

Balancing Loop B2: Cloud Technology Absorption

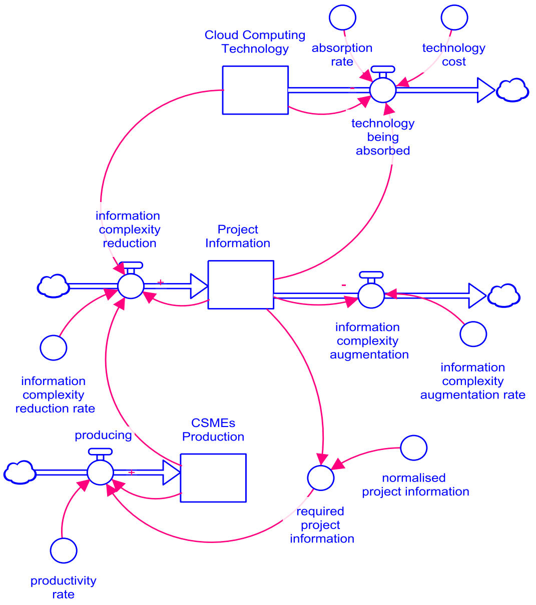
The balancing loop (B2) implies that a decrease in 'Project Information' prompts the CSME to absorb technology shown by the causal link 'technology being absorbed' which eventually leads to the absorption of 'Cloud Computing Technology' including cloud collaboration tools. 'Cloud Computing Technology' absorption increases the 'information complexity reduction' which increases the 'Project Information' flow on construction site. There is also an exogenous influence which is the cost of the cloud computing technology shown by 'technology cost', however, the cost being negligible does not affect the CSME in the absorption of cloud computing technology.

Reinforcing Loop R2: Productivity Improvement

The reinforcing loop (R2) shows an increase in 'Project Information' flow facilitated by ‘Cloud Computing Technology’ (using cloud collaboration tools through smart phones, tablets and laptops) which results in an increase in 'producing' levels leading to productivity improvement resulting in an increase in 'CSMEs Production' on construction sites. An increase in 'CSMEs Production' leads to an increase in the 'information complexity reduction', and closes the feedback loop.

The CLDs provide a representation of the complexity of information and necessary measures to manage the complexity, through the improvement of project information flow. The CLD provides a dynamic hypothesis and forms the basis for the stock and flow diagrams (SFDs). The SFD is a formal approach towards addressing the problem.

Figure 5: System Dynamics Model

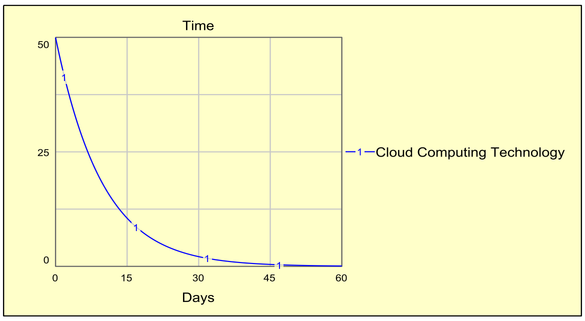


The model consists of stock and flow diagrams with feedback structure. It consists of three main components, which include 'Cloud Computing Technology', 'Project Information', and 'CSMEs Production'. The SD model shows that the absorption of CC technology (including cloud collaboration tools) using digital devices, such as smart phones, tablets and laptops, increases project information flow. The improved information flow leads to improved productivity for CSMEs. The SD model was developed taking the findings from the pilot study into consideration. The model will be further developed following the main study incorporating variables, including endogenous and exogenous factors.

SIMULATION RESULTS AND DISCUSSION

The SD model was validated by the construction SMEs in the sample who were the participants of the pilot study through focus groups. The model consists of three main components including 'Cloud Computing Technology', 'Project Information', and 'CSMEs Production'. The simulation represents the behaviour over time graph, which illustrates the absorption of 'Cloud Computing Technology' as shown in figure 6.

Figure 6: Cloud Computing Technology



The graph represents the corresponding increase of 'Project Information' due to absorption of 'Cloud Computing Technology' illustrated in figure 7.

Figure 7: Project Information

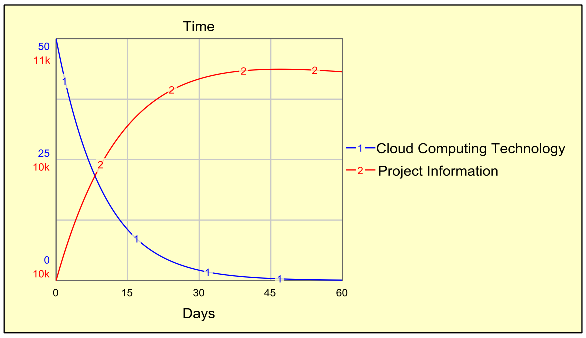
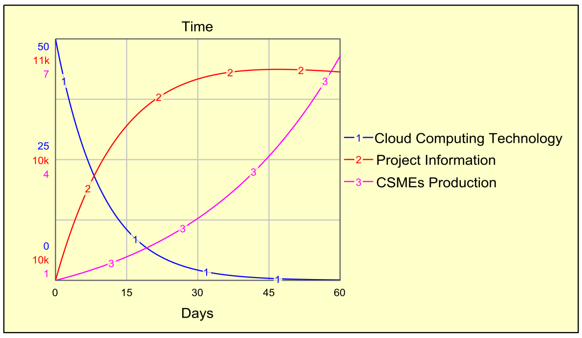


Figure 8, illustrates that an increase in absorption of 'Cloud Computing Technology' results in an increase in 'Project Information' leading to productivity improvement resulting in an increase in 'CSMEs Production', ensuring greater information mobility using digital devices, such as smart phones, tablets and laptops on construction sites.

Figure 8: CSMEs Production



CONCLUSIONS

The transfer of effective information and data on construction sites has become more complex with more parties involved and greater interdependence of digital information. More effective collaboration is required between all organisations involved in a project, recognising the long and interrelated production and supply chain. Cloud computing is a collaboration-enabling technology that provides a platform to cloud collaboration tools, facilitating transfer of information and data using digital devices such as smart phones, tablets and laptops. The Hybrid-SaaS model is suggested, which is beneficial for both the specialist contractor and the main contractor having the ability to regulate accessibility to information.

System dynamics (SD) is an effective tool that was used to develop a model to help improve project information flow, leading to productivity improvement, through the absorption of cloud computing technology and cloud collaboration tools for CSMEs. The model is useful for the speciality contractors, it provides a system and procedures with feedback loops that has the potential to provide and capture real-time information on performance and productivity. The SD model is based on the findings of the pilot study and will be further developed in the research.

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