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Simulating the dynamics of social agents and information flows in BIM-based design

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ABSTRACT

Design work entails collaboration that increasingly requires dynamic and complex information exchanges among multi-disciplinary teams. Although Building Information Modelling (BIM) is frequently advocated as a solution to myriad issues, poor workflow still plagues the design process resulting in rework, delays, cost overruns, and errors which are detrimental to the project. This can be attributed to a lack of consideration of inherent problems in communication and behaviours of design teams when adopting BIM. This study aims to examine whether BIM adoption can improve design workflow by concurrently considering social interaction mechanisms and information flow dynamics. Accordingly, the research method adopts agent-based modelling and social network analysis to analyse and measure information flow in BIM-based design. Cross-analyses of results from a case study indicate that using BIM as production tool does not explicitly improve workflow or achieve the full potential unless fundamental conditions are present, namely collaboration and changes in traditional mindsets.

1. Introduction

Design workflow is the flow of information, handoffs of deliverables, requirements, specifications, calculations, and design solutions among individuals and teams. Today's design processes have become increasingly complex with the advancements in design specifications, end-user needs and preferences, as well as the multitude of involved systems and teams. In addition to these factors, advanced software and hardware capabilities result in the rapid proliferation of information and data during design. This fast and large production of information quantities, coupled with constraints placed on deadlines and budgets, is likely to yield design errors and conflicts. Furthermore, the complexity of managing design is exacerbated due to the involvement of multiple individuals and teams with different specializations and geographical locations [1]. Consequently, the complex design process and the rapid information boom can jeopardize the proper design workflow between teams. Poor design flow, in turn, results in various types of waste such as excessive rework and revision cycles, errors in designs, reduced quality, cost overruns, and schedule delays; all of which diminish the generated value for end-users [2,3].

Given this design complexity, the dependency on traditional design management methods is incapable of alleviating the resulting poor design performance [4]. These methods mainly focus on traditional functional elements of planning, organizing, budgeting, leading, and evaluating to achieve time, cost, and quality objectives [5–8]. Moreover, these methods emphasize on the transformation process (i.e., converting design inputs into deliverable outputs [9]) and task completion while neglecting information flow and value generation. This traditional transformation process leaves a vague understanding of what happens within it and does not consider the detrimental consequences of disregarding information flows [2,10]. Such consequences, mainly design inefficiencies, inferior quality, rework, improper communication, and non-value adding tasks, impose an urgent need to ensure proper workflow throughout the design phase to avoid interruptions and wasteful transformation processes. This is where the Transformation, Flow, Value (TFV) theory came forth to highlight the important role of information flow in the transformation process and generating value within it [8]. Therefore, what design management really entails is the management of people and the flow of information between individuals and teams.

In this regard, the main challenge in design projects is how to manage work flow and people [2,11]. Some recent advances, specifically Building Information Modelling (BIM), aiming at integrating information into virtual models to facilitate the design, construction, and facility management of projects have been developed. Although BIM is frequently advocated as a solution to myriad design issues and for supporting better information sharing and collaboration across teams, poor workflow still plagues the design process. This can be attributed to a lack of consideration of inherent problems in communication and behaviours of design teams when adopting BIM. Given the complex

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interdependencies of the people involved as well as the information generated, a new perspective is presented in this study that considers this complexity and integrates the social aspects of people's interactions with the exchanged information. Therefore, this study aims to examine whether BIM adoption can really improve design workflow by concurrently considering social interaction mechanisms and information flow dynamics. Accordingly, the research method adopts agent-based modelling and social network analysis to measure, analyse, and better understand the underlying dynamics and factors impacting design workflow resulting from BIM use. This dual method allows to model the exchange of design information between the members of different teams to capture a holistic view of the complex interactions and processes involved in the BIM-based design process.

This study can change the way design workflow has been previously analysed so that underlying problems and root causes can be identified and linked to the observed workflow trends. In turn, the insights gained can enable decision makers and managers to take the right actions to enhance workflow by targeting these causes and problems. This research also extends the knowledge on BIM-design processes and what conditions and prerequisites should be present to ensure better design workflow when adopting BIM.

2. Research background

2.1. Design workflow characteristics and problems

Design attributes, whether in the building sector or product engineering fields, converge towards the same understanding of their processes. These characteristics have been described in various literature as design being: *ill-defined, iterative, complex, uncertain and variable, and a transformation, flow, and value generation process* [10–15]. Design tasks and information exhibit different kinds of interdependence. Thompson [16] examines these interdependencies and classifies them into three types, *pooled, sequential,* and *reciprocal*. Bell and Kozolowski [17] introduce a fourth dimension of interdependence called *intensive interdependence*, where tasks and information form a web of input and output loops that require high levels of coordination within and between teams. However, past research and traditional processes do not commonly consider the importance of information flow and interdependencies between designers which results in poor workflow practices. Informal surveys conducted with design teams revealed that negative iterations (rework) constitutes an approximate 50% of design time [18]. Design rework is work that is performed again at least one extra time to amend original design to ensure it conforms to the requirements. Such rework is usually due to obsolete or wrong data, as well as missing information that was not promptly shared. Failing to realize these inherent design characteristics can hinder the essential collaboration and interactions for proper design workflow. Accordingly, managing the design process in such a way that considers these critical interdependencies and design attributes is vital for the successful execution of design and the fulfilment of the client's value.

2.2. Current workflow management

Recent research efforts have examined new ways of managing design taking into consideration the involved workflow and/or the interactions among design participants. In this regard, Al Hattab and Hamzeh [19] have developed swim-lane process flow diagrams to show the flow of design output deliverables across different design stages and respective teams under ideal BIM-based and traditional design in attempt to qualitatively demonstrate differences in information flows at a macro level using BIM. Discrete-event models have been employed to simulate construction design tasks and data flow diagrams were developed to model tasks with their information requirements during the design stage [20]. Similarly, Chua and Hossain [21] developed a simulation model to study the impact of early information sharing to reduce design duration and avoid redesign downstream, reemphasizing the need for better information sharing. *However, previous studies do not study the role of collaboration and social interactions as important parameters in the success of early sharing and shaping workflow, a matter which this paper majorly considers when assessing information exchanges under BIM.*

Measuring performance is an important step to assess design workflow and implement the required changes. In this regard, some studies have developed lean indices for measuring information flow on construction projects by mapping the sharing trends of data collected from database logs of the detailed design phase [22,23]. *However, they are not very comprehensive nor sufficient, making it hard to measure performance. In addition, these studies neglect a critical controlling factor in the process: individual behaviour, and team behaviour, and interactions.*

On the other hand, some studies have reconsidered design activities from a networked perspective, where the people performing those activities are considered and how their behaviour can affect performance [24]. The design activity network and organizational social network of people, in the mentioned study, are integrated where the responsible people are mapped to their activities. This study was then expanded to analyse design activities through the stages of complex engineering design using different social network analysis (SNA) metrics characterizing the impacts of human interactions on these activities [25]. Although these two efforts have shed light on the importance of social interactions and the human factor in shaping the design process, they do not incorporate the information dependencies of design activities and their exchanges between involved individuals. Moreover, social network structures were analysed in hierarchical organizational setups to study the impacts of different organizational compositions on the flow of information to different members of the hierarchy [26]. Durugbo et al. [27] have developed a mathematical model of information flow for analysing collaboration in organizations by developing social network metrics pertaining to collaboration, teamwork, and decision-making. Although these studies provide insights into a member's position within organizational networks and the amount of information reaching them based on their hierarchy, they do not demonstrate the actual flow of information resulting from dynamic exchanges between individuals and are only based on static and mathematical relationships. *Based on these studies, it is evident that the intersection of flow dynamics and interactions between design individuals is not fully considered when studying workflow where some only consider the social network while neglecting the flow of design information, while others only analyse information diffusion and ignore team coalitions.*

Accordingly, there is a tendency to separate workflow from the human interactions involved. Yet, the studies that did include the social networks only considered the integration with design activities and disregarded the information requirements and dependencies within these processes. This can be potentially attributed to the fact that information flow varies across different projects and the expected value of mapping detailed exchanges is not justified or clear. Despite these concerns, it is important, for design to be successfully delivered, to dynamically integrate design information with social networks to analyse and measure how such information is diffused due to human interactions and collaborations. The results of taking on such a detailed study, even if project-specific, can reveal new insights and set new frameworks for dealing with today's complex BIM-based design processes. Therefore, analysing information flow in BIM-based design through a new integrative perspective is fundamental for improving design management because it can detect underlying problems in workflow so that corrective measures can be proposed for resolving them.

2.3. Social network analysis (SNA) and agent-based modelling (ABM)

Social network analysis (SNA) is an approach for focusing on the relational structures of systems within which entities exist. It is a