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MODELING DESIGN WORKFLOW: INTEGRATING PROCESS AND ORGANIZATION

Malak Al Hattab[1] and Farook Hamzeh[2]

ABSTRACT

The advancement and increasing complexity of design requirements result in the rapid proliferation of information that needs to be properly integrated and coordinated among multidisciplinary parties. Inefficient planning, the ill-defined and iterative design nature, and poor communication disrupt design workflow, consequently creating waste such as increased cycle times, cost, rework, and errors. Sub-optimal design workflow has captured researchers' interests who have developed frameworks tackling design task structuring, measuring flow, or understanding the organizational network involved. However, a formerly unexplored perspective is one that integrates both the process, i.e., flow of design information, and the social network, i.e., interactions among design teams. This integration and communication between teams enables the design intent to properly flow and be transformed into value adding output. Accordingly, this study approaches workflow at the intersection of the social and process aspects of design to understand, measure, and analyze information flow within communication networks. Agent-based modeling and social network analysis are used to dynamically capture the impacts of lean practices and Building Information Modeling (BIM) on communication. This novel design management strategy focuses, simultaneously, on interaction dynamics and information diffusion to assist design teams in enhancing design flow, knowledge transformation, and value generation while reducing wastes.

KEYWORDS

Work flow, communication, lean design management, Building Information Modeling (BIM), Agent-based modelling (ABM).

INTRODUCTION

The design phase is considered to be one of the most challenging processes as it is concerned with the creativity and efforts of human minds in order to create, innovate, test, and transform ideas and inputs into value adding services, products, or facilities for clients or end users. Any deficiencies and complications resulting from design can have

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detrimental impacts throughout the project' life cycle. In fact, the highest levels of effort and influence on the project are attributed to the early design stage (Macleamy, 2004), whereas the cost of changes is the least during early design. Therefore, the proper management of building design is critical for ensuring a successful delivery of projects as the impacts of design propagate and augment when moving downstream along the project's phases.

BUILDING DESIGN CHARACTERISTICS

Building design is characterized by a high level of uncertainties due to the ill-defined nature of requirements, solutions, or outputs. Design requirements can be well understood, whereas the solutions and resulting outputs cannot be defined in advance and are generally vague at the beginning. The "wicked problem" case happens when the requirements, solutions, and outputs are all ill-defined, unpredictable, and poorly understood. Moreover, design tasks and efforts are iterative in nature. Multiple alternatives are considered, developed, evaluated, and reconsidered or discarded in order to reach an unconstrained and satisfying set of solutions (Maier & Storrle, 2011). Additionally, the intensive interdependence of design information and tasks of a large number of trades, makes design further complex.

Furthermore, the design environment is built on the interaction and communication of multi-disciplinary teams whose processes and information are intertwined. With the increase in interdependence and complexity of design tasks, the need for more synchronous communication becomes vital (Knotten et al., 2015). Therefore, design management should be targeted to address these specific characteristics of processes and teams involved for a proactive navigation of the project towards its successful completion.

The complexity and interconnectedness of design make real time information exchange, transparency, and flowing with changes a necessity for design management. Traditional project management has ignored the needs for design management, specifically design workflow management, where upstream design disciplines neglect the needs of each other as well as the needs of downstream disciplines. In fact, project management is solely concerned with the transformation process and task completion with little to no attention given to workflow and value generation (Ballard, 2002; Ballard & Koskela, 1998). Therefore, relying on the same management techniques can be counterproductive. The efficacy and challenge of design management is rooted in appropriately managing its work flow.

DESIGN WORKFLOW MANAGEMENT

Managing design workflow has to do with managing the people involved in the design process as well as the flow of information between them to enable for design solutions to progress. When planning design tasks, the lack of consideration of their interrelatedness often leads to tasks being planned with insufficient, obsolete, or faulty information, leading to poor productivity, delays, cost overruns, and an inferior ability to generate value for the client or end user.

The rapid proliferation of information needs to be properly integrated and coordinated among multidisciplinary parties. Failing to plan and relate information flows to the respective tasks and responsible parties, delays in sharing the right information can result in delaying the progress of design task completion, out-dating existing information, and causing design deliverables to have missing data necessary for their conformance with requirements or completion. Unfortunately, such issues are usually concealed and only appear in later stages of construction, where the cost, time, and resources required for changes and rework are high. A study by Al Hattab and Farook (2015) examines the impact of design communication and BIM-lean use on the management and reduction of design error diffusion that usually results from poor design workflow.

Sub-optimal workflow has captured researchers' interests who have developed frameworks tackling design task structuring, measuring flow, or understanding the organizational network involved. However, a formerly unexplored workflow perspective is one that integrates both the process, i.e., flow of design information, and the social network, i.e., interactions among design teams. Accordingly, this study approaches workflow at the intersection of the social and process aspects of design to understand, measure, and analyze information flow within design networks. Lean practices and BIM functionalities can enable, through their focus on team work and information integration and sharing, a better design workflow. Agent-based modeling and social network analysis are therefore used to dynamically capture the impacts of lean practices and BIM on communication. This novel design management strategy focuses, simultaneously, on interaction dynamics and information diffusion to assist design teams in enhancing design flow, knowledge transformation, and value generation while reducing wastes.

GAPS IN CURRENT WORKFLOW APPROACHES

When addressing design workflow, some studies tend to isolate the topology of team interactions from the flow of information between individuals by only considering design task transformation while neglecting the flow of design information, or by targeting the social network structure of involved individuals and ignoring information diffusion, or by analyzing information diffusion and ignoring team coalitions. Some gaps in existing research are presented below and summarized in Figure 1:

Research and industry do not commonly consider the importance of information flow 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 (Ballard, 2000). Obsolete or missing information that was not promptly shared can result in such rework. During conventional design, individuals and teams work in isolation without realizing that information they are withholding is useful for other team members and the overall design requirements.

The drawbacks of poor workflow are not clearly understood or observed which limits instilling flow into design practice. Some studies developed flow diagrams to qualitatively map the flow of design deliverables through different stages of the design process (Baldwin et al., 1999). However, this flow has not been mapped across multi-disciplinary teams to highlight the interactions between trades with diverse needs and outputs. Therefore, the impact of these relationships on information flow was not thoroughly evaluated.

- Current methods for quantifying flow metrics are not very comprehensive nor sufficient, making it hard to measure performance. Measuring performance is an important step to assess design workflow and implement the required changes. Tribelsky & Sacks (2011) developed metrics to measure design information flow rates on projects by tracking database logs and showing trends of indices reflecting design workflow. Such studies provide important metrics to understand information flow patterns based on database logs, yet they neglect a critical controlling factor in the process of information flow: individual and team interactions. Social network structures and their impact on flow of design work and design quality are not taken into account when measuring information flow.
- The intersection of flow dynamics and interactions between design individuals is not considered when studying workflow. Some studies highlight the importance of realizing design and construction projects as social networks constituting design players and their communication (Pryke, 2014), whereas others extend this notion to develop a modeling method that links design tasks to the responsible people within a social network (Parraguez, Eppinger, & Maier, 2015). Some efforts developed metrics of collaboration and team work and related them to the ability of information to reach people depending on their position in hierarchical networks (Lopez, Mendes, & Sanjuan, 2002; Durugbo et al., 2011). Although these studies give insight into the integration of design activities and people involved, they do not model the information exchange necessary for performing tasks, which prevents the realization of workflow patterns within such networks.

As a result, this study is driven by the urging need to address these problematic areas and explore a new approach that accounts for the dynamics of information flow within social networks. It also puts forth a way to assess the impacts of lean design management and BIM-based design on leveraging workflow of conventional design by enabling more interaction, transparency, better communication, and real-time exchange of information. Achieving better workflow can potentially reduce common design wastes such as rework, long cycle times, bottlenecks, and defective designs.

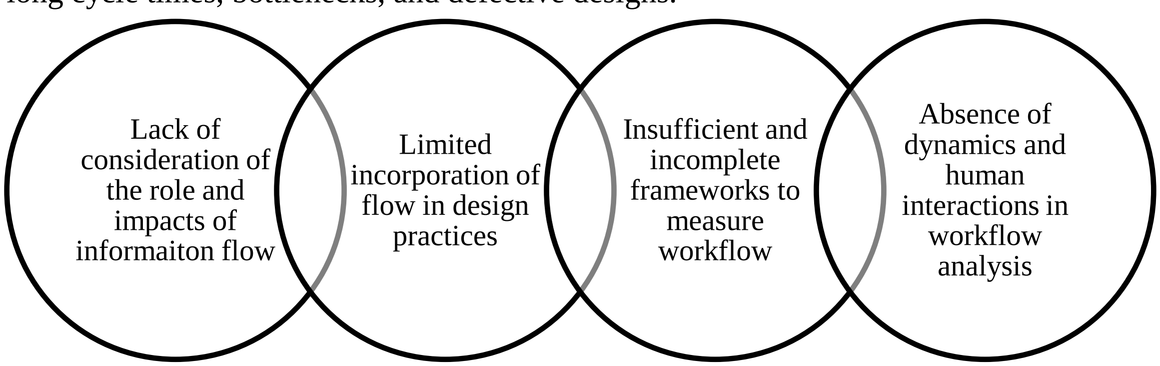

Figure 2: Gaps in design workflow research

AN ALTERNATE METHOD FOR MODELING WORKFLOW

The new method presented in this paper integrates the social and process perspectives to study design workflow. Agent-based modeling is used to reflect the complexity of the design process: the social network topology and design information dynamics. Building design is an intricate system consisting of many individuals working within geographically dispersed teams with different skills who are all gathered to deliver a project with limited time, cost, and information. With current shifts from traditional project delivery to the adoption of lean philosophies and BIM-based technologies for life-cycle management, it becomes obsolete and ineffective to analyze design workflow independent from the interactions of teams that bring about the design delivery process.

Agent-based modeling (ABM) is a new approach for simulating the behavior and interactions of autonomous agents with complex interdependencies. Agent-based modeling is the simulation of occurrences as dynamic systems of interacting agents to analyze their collective behavior within a system in order to understand underlying phenomena and apply certain improvements for the whole system and individual agents as well. Agents can represent people, cars, information, resources, companies, atoms, etc. ABM regards the modeling of agent interactions and relationships with other agents as well as modeling its behavior which depends on the situation and environment it exists in (Macal & North, 2009). ABM allows us to capture the emergence of new behaviors and performances resulting from aggregate interactions and dynamics of agents, which is not possible to inspect separately within complex and highly intertwined systems.

The system considered is a social network, depicted schematically in Figure 2, consisting of two types of agents: (1) the person (design participant) agent and (2) the design information deliverable agent. This topology represents nodes as the people performing design or involved in the design decision-making process, links (edges) as interactions and communication between the people agents. These links, in earlier studies, have been regarded just as mere connections and what flows within them has been disregarded. Figure 2 shows a schematic representation revealing what flows during design within this vague box of transformation.

These interactions as well as the exchange and interdependence of information create an emergence of new information flow patterns. Using social network analysis (SNA), these interactions and the topology of connections between designers helps visually understand some characteristics of the social network structure. Not only does SNA examine the structure of the network, it also studies the natural mechanics occurring within. SNA helps researchers understand the network data visually, convey the results of the analysis, and reveal any hidden properties that might not have been captured through qualitative analysis. Quantitative assessments can also be performed for relationships, connections, and characteristics pertaining to an individual node and to the network structure as a whole using some metrics presented in Table 1. Such metrics reflect the environment of communication, where individuals might work as cooperative teams or as isolated entities, exist as segregated clusters or one coherent network unit, work within a centralized or decentralized decision making hierarchy, facilitate the flow of information or make it interrupted based on their interactions. Other insights can be obtained through the observation and analysis of network topologies.

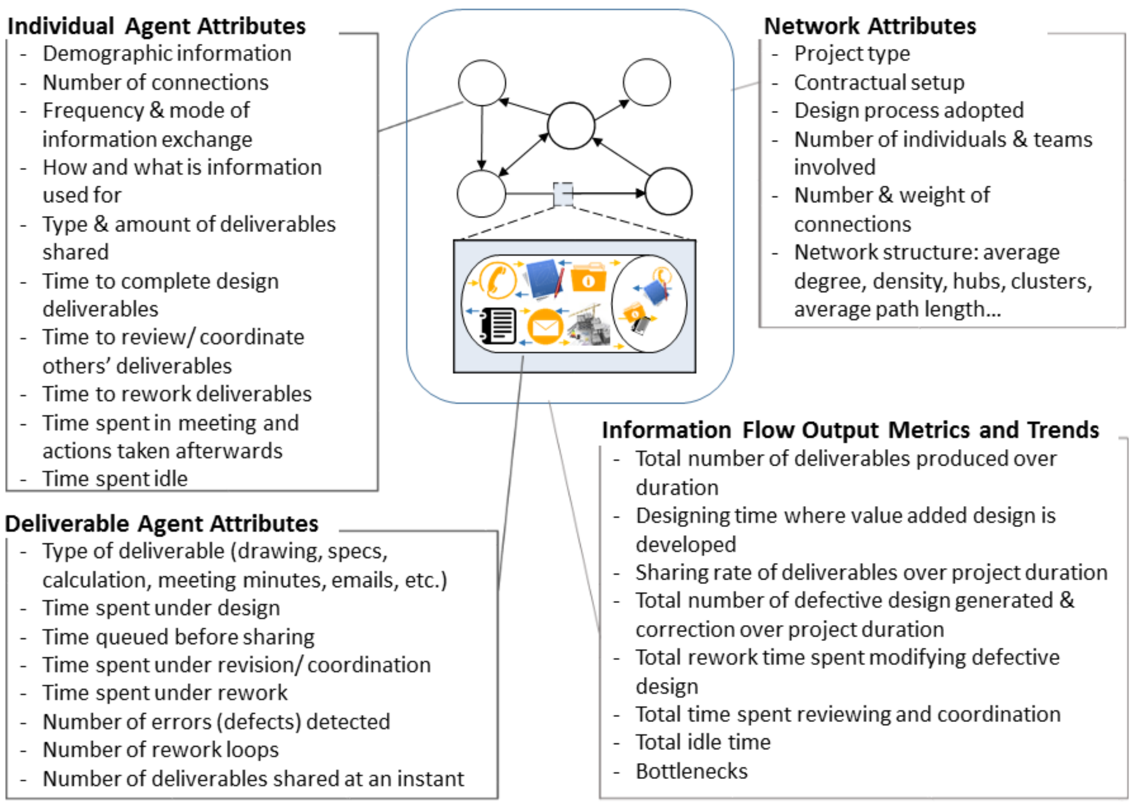

Figure 3: Social network topology, agents' attributes, and output metrics

In the topology presented in Figure 2, and in order to account for information flow within these links, an information deliverable agent is created representing design information deliverables such as BIM models, design drawings, calculations, emails, meeting minutes, etc. While ABM takes a reductionist approach that transforms the real world into a simplified model, it more importantly allows us to capture emergent behaviors of the overall network behavior that cannot be obtained by simple observations or assumptions of individual agent behavior, better understand how design information flows between participants, and underline the role of the social structure in influencing the diffusion of design information. By measuring and analyzing the behavior of individuals and information flow within the entire network through ABM, unpredictable outcomes that are hard to see are made clearer and more understandable. Traditional analytical methods fail to capture the resulting emergence of collective behavior and dynamic relationships between agents, and they usually represent a static description of the system at one frame in time. These limitations of regular approaches discussed earlier lend the need to use agent-based modeling to model the behaviors, interactions, exchanges, and formations of teams and organizations that influence individuals and the overall system emerging performance.

Table 2: Social network metrics

Type	Metric	Definition (this metric describes)
Node	Degree centrality	Measures the number of links an individual has with others
	Betweenness	Measures the number of node pairs that an individual connects or bridges (serving as a broker or intermediary)
	Closeness	Measures the number of links from an individual to others; how reachable a person is by others
Network	Density	Measures how many actual links exist between nodes divided by the number of total possible links to reflect cohesiveness of the network
	Clustering	Measures how clustered groups of people are compared to the rest of the network indicating existence of closed triads and small communities
	Average path length	How many steps, on average, nodes require to reach each other
	Modularity	How dense the connections between nodes within groups as compared to nodes with other groups

ABM SETUP FOR LEAN-BIM BASED WORKFLOW

AnyLogic is a simulation tool that performs discrete-event simulation, system dynamics, and agent-based modeling. AnyLogic is used in this study to develop a model for understanding and measuring design workflow resulting from lean and BIM-based design network topologies. The model interface consists of two agents that were defined earlier (people and information deliverable agent). The behavior of each agent is represented through a "State Chart" that defines the behaviors or states of each agent, and provides the rules for changes in behavior and interactions with other agents.

A person agent can have these interchanging states: "designing, integrating/coordinating, reworking/modifying design deliverables, sharing deliverables, in a meeting, being idle". The interchange or transitions from a state to another, as shown in Figure 3, is dictated by interactions and requests from other people in the design process. For example, if a person is designing and someone requests input from him/her, he/she moves to the "Share" state after completing a certain design. The time invested in each state, and the transitions between states, are based on data that can be collected through surveys and observations of individuals and teams. The behavior of each agent throughout the project can then be simulated to show the changing dynamics throughout the design project and how the design process and exchange of information is flowing within the design network.

Similarly, the information deliverable agent possesses a different set of states. This agent exchanged between designers. This kind of agent is a mobile agent (it is transferred and exchanged) and its behavior is controlled by the behavior of its superior agent (designers). An information agent can have these states: "In progress, ready for sharing, ready for coordination, under integration/ coordination, approved, clashes detected, or under rework". The interchange or transitions from a state to another is dictated by the decisions and behaviors of the designer agents. For example, a BIM model, moves from "Ready for coordination" state to "Under integration/ coordination" state when the people responsible for coordinating it start the "Integrating/coordination" state process. Data pertaining to the number of BIM models and deliverables exchanges over a time period, whom each person exchanges information with, how frequently deliverables are exchanges, the means of communication, the number of revision cycles of a deliverables, and other input can be collected through questionnaires addressed to the designers and by tracking data logs of such exchanges. Figure 4 is a sample state chart of a BIM agent.

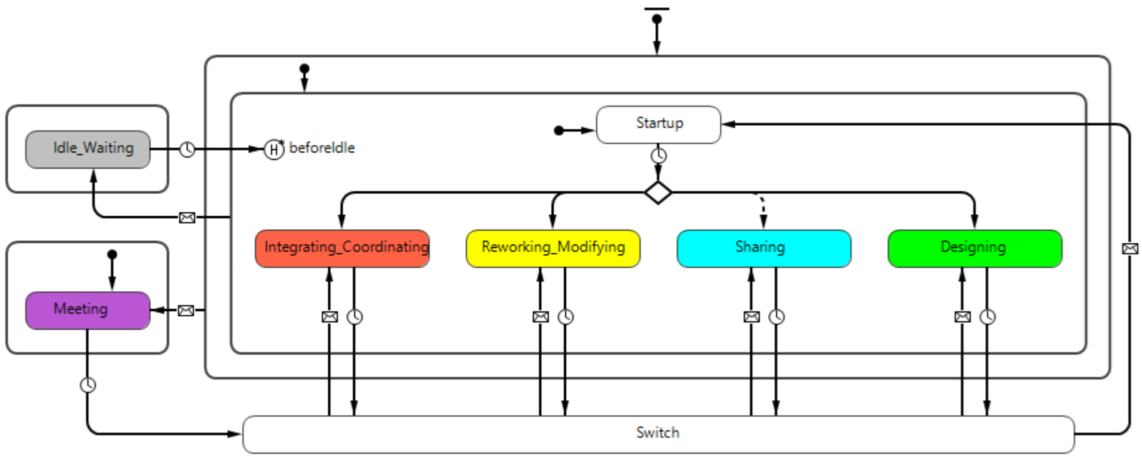

Figure 4: Designer state chart of behaviors

WORKFLOW ANALYSIS THROUGH SIMULATION OUTPUT

The characteristics of design workflow exchange of each individual, the state of each information deliverable, and the overall dynamics of information flow of the entire network can then be obtained. On the designer agent level, the simulation of the model can highlight interesting trends such as: the number and durations of design cycles which can help detect phases of idle time or non-value adding design and how time is divided between different design activities, number of rework and revision cycles conducted by the designer that can imply potential problems with design information and error diffusion mechanisms as well as conformance or non-conformance with design requirements and the introduction of client changes during design, and other attributes that can be explored in-depth in further research. Value-adding design workflow can be assessed from several lean perspectives, for example: sharing trends and frequencies which can reflect a smooth flow of information or batch interrupted flows that can result in efficiencies, queueing time experienced by information deliverables, the number of rework cycles which can reflect if information exchange patterns are efficient in delivering important data to the right people at the right time or turning data into obsolete information resulting in errors that require rework, and other trends that can reflect underlying issues in the communication processes involved in the design process. On the information deliverable level, the simulation can show the length of time a model can be held in queue with a designer before it is shared, reviewed, reworked, or before a decision is taken on it. Moreover, the number of times it is revised, reworked, modified, shared, and the number of errors or design non-conformances can be tracked for each deliverable.

On the collective network level, several insights that describe design workflow on social networks can be obtained. Figure 5 is a sample of project sharing trends. For example, patterns can reflect whether workflow is smooth or interrupted, whether information is being shared continuously between designers or stored in silos then shared in batched resulting in outdate data that can be later manifested as errors in other deliverables. Bottlenecks in processing times (reviewing, coordinating, designing, or sharing) of individuals or teams can also be detected and help indicate where actions need to be taken. The overall quality of design information reflected in the dynamic generation and diffusion of errors between teams over a time span can also be observed to highlight root causes of resulting trends. In addition, design information production patterns can show when and how information is being produced, stored, queued, and can provide insight on drivers or preventers of design generation. Further insights on design workflow attributes and the influence of interactions and topologies of networks can be explored.

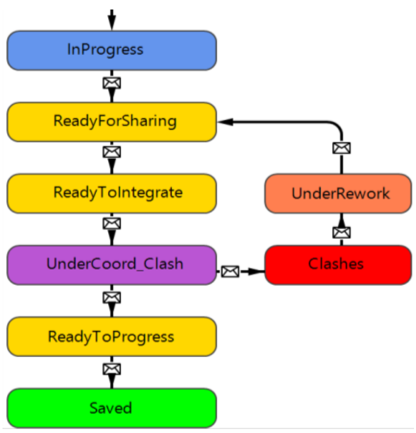

Figure 6: BIM model state chart

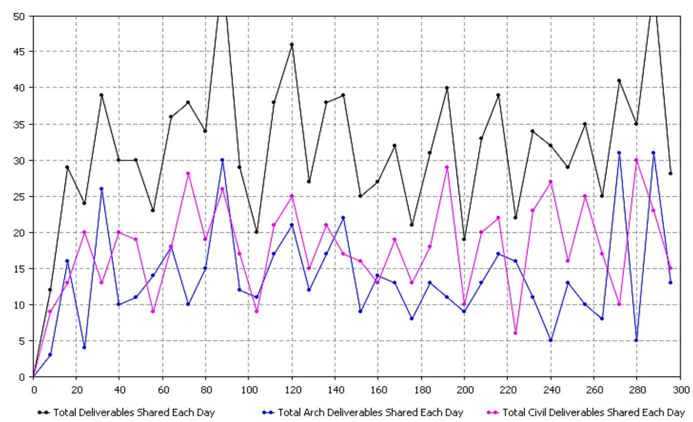

Figure 5: Project design information sharing trends

CONCLUSIONS

The proposed method of integrating social topologies and design process dynamics through ABM can provide a different perspective for understanding the diffusion of information between parties involved in the design process. The developed approach is an attempt to improve on and bridge the gaps of the existing methods to accommodate complex systems in terms of involved teams, sophisticated requirements, integrated technological interfaces, and large amounts of information that needs to be coordinated and effectively exchanged. The social network topology metrics and the resulting patters of workflow dynamics can be cross-checked to highlight potential relationships of communication and team coalitions on shaping the quality and flow of information. Moreover, the proposed approach can allow for a quantitative and qualitative analytical comparison of lean-BIM design processes to traditional design trends. These comparisons can set a working standard, highlight potential benefits resulting from lean-BIM use, and benchmark performance to desired standards. This analytical method can be further explored on the project-life cycle as a whole and tailored to model complex interdependent systems that are continuously changing over time.

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