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A CONCURRENT DESIGN PARADIGM FOR INTERDISCIPLINARY DESIGN COLLABORATION: INSIGHTS FROM A FOCUS GROUP STUDY

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Abstract

Current building design collaboration follows a siloed and sequential workflow, leading to cumbersome manual rework, multiple files and versions, onerous coordination tasks, etc. Designers struggle to meet the demands of modern construction projects in terms of time, cost, quality and sustainability. Interdisciplinary collaboration can be greatly improved through a new paradigm that entails synchronous collaboration with reinvented functions within BIM technologies. To explore this new paradigm, we adopted the design science approach with five steps: (i) literature review, (ii) mockup design, (iii) survey distribution, (iv) focus groups, and (v) data analysis. The results validate the importance of inter-domain design change, strongly support the case for the utility of the use case scenarios, and recommend several directions for future research.

Introduction

Design collaboration across different disciplines is a significant challenge in the Architectural, Engineering and Construction (AEC) industry (Oh *et al.*, 2015). During the detailed design phase, designers are often required to adapt their designs following changes made by other disciplines (Mohd Nawi *et al.*, 2014). While design changes are intended to improve the quality and accuracy of the model, they often result in manual rework, cause delivery delays, and lead to inconsistencies across models, ultimately reducing the quality of the project outcome (Yap and Skitmore, 2018). Therefore, improving interdisciplinary design change collaboration in the detailed design phase is a critical aspect of research in next-generation systems. However, despite the application of advanced technologies (e.g. cloud and agent technologies) (Afsari *et al.*, 2017; Shen, 2019) and information exchange solutions defined in ISO19650 (Winfield, 2020), current BIM solutions still adopt a file-based and sequential collaborative workflow that hampers real-time, transparent information exchange across disciplines. In addition, the current asynchronous collaboration methods used in common data environments often create inefficiencies and delays in the design changes process (Esser, Vilgertshofer and Borrmann, 2022).

Significant improvement to interdisciplinary collaboration may require disruptive changes in both the collaboration workflow and the supporting technological environment. This approach has the potential to enhance the design changes process by enabling real-time collaboration and communication between stakeholders from different domains. As such, Sacks *et al.* (2022) have proposed a new paradigm of cloud-based BIM environment that aims to drive better design collaboration across disciplines by adopting graph representation, semantic enrichment, cloud and agent technologies, etc. This paradigm claims to fulfil a new mode of collaborative design and detailing, allowing designers from different disciplines to use their own BIM tools to design, check consistency, authorise, analyse and manage versions at the object level. Specifically, designers and detailers can carry out the functions as follows:

- Design and model: Develop models and product information using their familiar concepts, relationships, and behaviours using discipline-specific software tools. Federated models are generated by designers in parallel.
- Check consistency: Solicit an alert when information is generated or changed by a collaborator from a different discipline that is incompatible with their current representation of the building.
- Authorise: If a conflict arises, the system can propose actions within its model or within the models of the other design domains. System changes and/or actions that conflict with the user's design can be reviewed, rejected, modified, and accepted.
- Manage versions: Coordinate sets of objects in the design with those in other disciplines using multiple alternative versions.
- Analyse: Perform a global design optimisation by combining different design versions with different run performances.

This paper aims to investigate if and how this envisioned paradigm might drive better collaboration for interdisciplinary design change in the detailed design phase. To achieve the aim, two objectives should be met, as follows:

- Understand what role interdisciplinary design changes play in design collaboration.
- Elicit and assess BIM adopters' attitudes to the proposed paradigm.

The rest of this paper is organised as follows: we first outline our research method in the Research Method Section. Afterwards, the Analysis and Discussion Section discusses the initial research results, including the description of the analysis and findings. Finally, the last section summarises the research contributions, limitations, and future work.

Research Method

This section is divided into two parts. It begins with the design science process adopted in this study, explaining the reason why such a method was adopted. Subsequently, it illustrates each step of the process, including scenario and mockup design, survey design and distribution, and focus group design and discussion.

Design Science Process

Design science aims to develop and validate prescriptive knowledge through research (Johannesson and Perjons, 2021). According to Herbert Simonn (1988), the natural sciences explain how things are, while design sciences design artefacts to achieve goals. In engineering research, it is a valid method for developing solutions to practical problems (Peffers *et al.*, 2007). It is also particularly suitable for wicked problems which are human-centred, exploratory, uncertain and lack data availability (Hevner *et al.*, 2004). This research topic fits the definition of a wicked problem in the following ways.

First, it is "human-centred" because envisioning future ways of BIM-based collaboration requires a deep understanding of the actual BIM users' needs and habits. Second, it is "exploratory" because the problem and the solution are not clear enough for everyone to agree upon. In addition, it is "uncertain" because it is hard to predict what the future BIM-based collaboration would be like with the current BIM technologies. Finally, "data availability" is a problem since it is difficult to directly obtain the right and sufficient data to validate the envisioned paradigm in the current commercial and technological environment. To conclude, these four attributes are the exact four prerequisites for a challenging problem to adopt the design science approach (Liedtka and Ogilvie, 2011).

Therefore, guided by the aim and objectives discussed in the Introduction Section, this research employed a design science approach consisting of six iterative steps: comprehending, observing, establishing a perspective, brainstorming, creating a prototype, and testing (Plattner et al., 2010). The careful collection of information about the problem identification in the activities "comprehending", "observing", "establishing perspectives" provides the basis for the solution development in the "brainstorming" and "creating a prototype" activities. The last activity, "testing", is the solution testing to evaluate previous knowledge. Through many iterations between different activities, the vision moved from ambiguity to clarity. We will discuss problem identification, solution development, and solution testing in the following section.

Implementation

In the following first sub-section, Problem Identification, including literature review, first-round interviews, and survey, we gathered insights about the problem domain and tried to understand what the most concerning use case is during detailed design collaboration. Afterwards, in the Solution Development Section, including literature review, scenarios and mockup design, and second-round interviews, we mapped the requirements to use case scenarios and designed low-fidelity prototypes. Finally, in Solution Testing, we tested the prototypes by conducting focus groups and analysing the interview data.

Problem Identification

After our first period of research with literature review and discussion, we proposed an ideal paradigm for BIM-based collaborative design, a cloud-based BIM environment (Sacks *et al.*, 2022). We believe this new environment can enable end users to design, model, check consistencies, and manage information exchange at the object level with their own BIM design tools. To investigate if and how this paradigm would drive better collaboration, we need to transform the abstract and technical definitions of the paradigm into concrete, specific, and practical artefacts. This allows practitioners to validate the paradigm in a situated context that realistically aligns with their daily experience. We accomplished this process in two ways: 1) making the problem specific by narrowing the scope and 2) making the solution understandable by prototyping.

Make the problem specific.

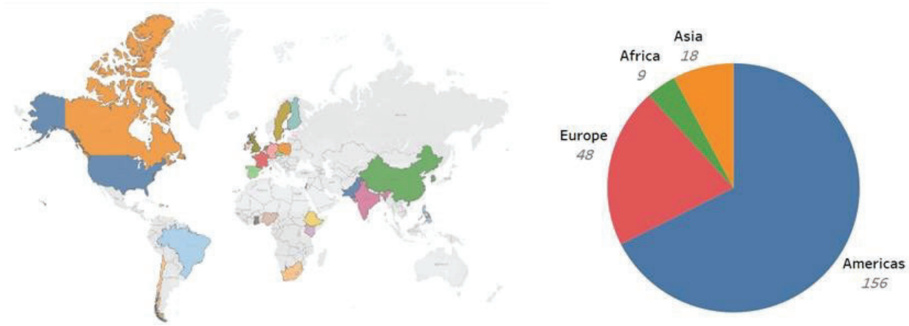
Design collaboration is a big scope. It is difficult to design a system that encompasses every aspect of a design collaboration in AEC. We will focus on the detailed design phase of this project since it is preferred to start with a phase with relatively more information to make decisions than the conceptual design phase. In addition, cost and time overruns are common in construction projects, and their causes can be traced frequently to the detailed design stage (Rathod and Sonawane, 2022). Furthermore, we needed a context and use case that can cover the major features of the concept. To understand the most concerning use case during collaboration, we conducted a first round of 10 one-on-one in-depth interviews with BIM experts to obtain insights, including not only BIM adopters and designers but also senior construction consultants, project managers and so on.

We also designed a survey to further validate if the use case covers the most central problems. The survey was distributed to BIM designers' communities on LinkedIn, lasting around one month, from 28th September to 28th October 2022. It served as both a questionnaire and a screening survey for the focus group recruitment. There were 231 responses from more than 28 countries and areas, as shown in Figure 1. The results show that inter-domain design change is one of the most important use cases during design collaboration since it covers a wide range of activities.

Solution Development

Make the solution understandable.

Prototypes are often considered to be more articulate than descriptions (Brooks, 2022). However, the requirements of multi-user software systems often restrict the potential of realising a tangible prototype due to time, cost and technical constraints. To solve this problem, we adopted a scenario-based prototyping approach developed by Meinel *et al.* (2011) to design a multi-user software



(a) Responses Distribution by Country *(b) Responses Distribution by Continent*

Figure 1: Responses Distribution

system, considering structural and behavioural aspects. This approach is conducive to the elicitation and validation of user requirements by visualising the interactions between users and the system. The scenarios developed in this process are not only indicative of the system's functionality, but they also serve as examples of the process and workflow.

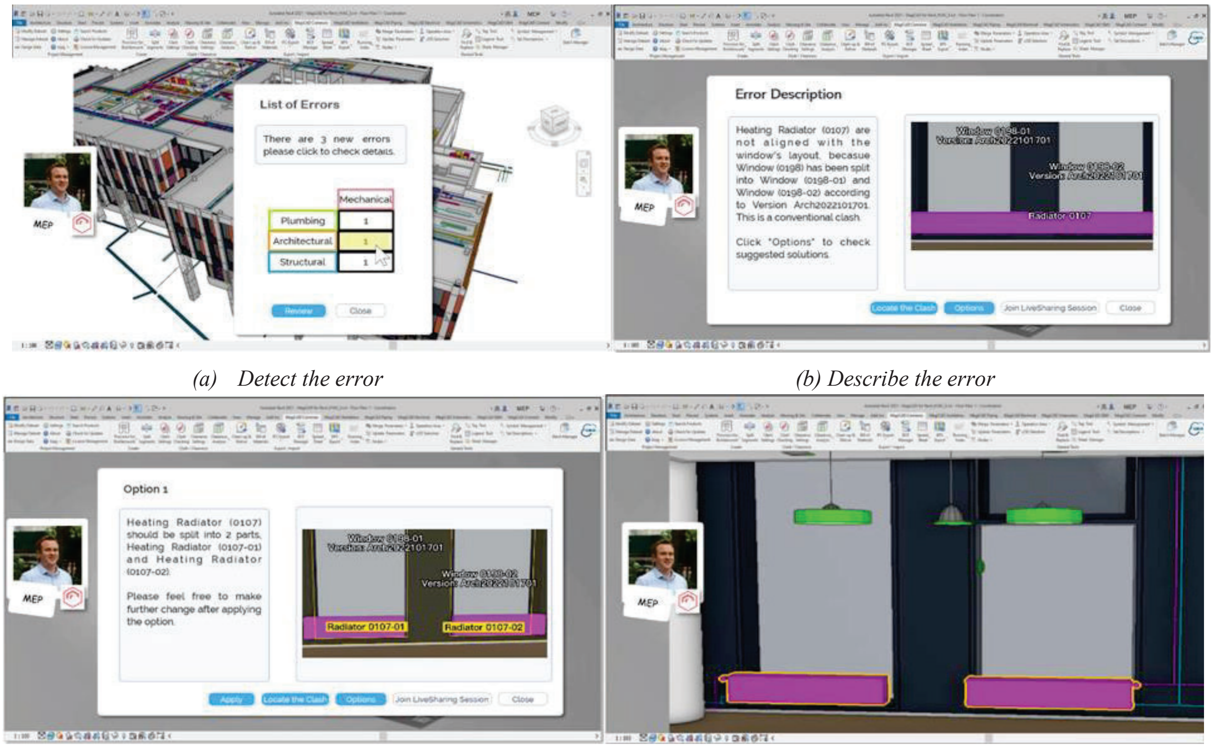
According to the interviews and survey results in the Problem Identification Section, inter-domain design change is one of the most important use cases during design collaboration since it covers a wide range of activities. Inter-domain design change in our research context stands for a series of design change relevant activities across disciplines. It is a lifecycle which contains the activities from the requirement that triggers a design change in one discipline, the action of design change itself, the actions of maintaining consistencies with this design change in other disciplines, to the actions of detecting and fixing all the clashes.

Based on the survey results and previous work (Sacks *et al.*, 2022), we designed the following four use-case scenarios with the corresponding solutions named after four functions. They are “Design issue avoidance”, “Design change management”, “Error correction”, and “Clash avoidance”. Afterwards, we mapped the four scenarios to the user interface (UI) mock-up prototypes. *Axure RP*, a design tool utilized for generating UX prototypes, was employed to design these mock-ups. The mock-ups were showcased to the focus groups through slide presentations accompanied by narrative explanations. Each scenario covers some of the features described in the paradigm concept. We will only convey the main idea of each function but not describe every scenario in detail due to the space limitation of this paper.

Design Issue Avoidance was designed to consider constraints, company codes, local regulations, project-customized conventions, etc., by bringing all the needed information on board as soon as possible. Usually, this function should be triggered right after the exact action of the inter-domain design change has been implemented by default. The role that needs to at first tackle the issue is usually the one who has made the design change. The main steps of this solution are to 1) detect the design issue, 2) notify the user, 3) propose solutions, and 4) authorise and apply a solution. The corresponding scenario describes how the architect and the structural engineer interacted through their own tools to implement a client's request for adding staircases that connect the 3^{rd} to the 6^{th} floor of a building. The system identified a possible design issue through the impact analysis that revealed that the structural engineer would need to modify the entire room structure to accommodate the staircases according to the architect’s new design change. The system informed the architect of the issue and presented the problem, offering the option for the architect to discuss a solution with the structural engineer. After receiving the solution from the engineer and obtaining the architect's approval, the system automatically implemented the solution. This system anticipates potential design issues and takes proactive measures to prevent additional efforts and communication between the designers. This ensures that the designers can work together to generate an optimal solution and make any necessary adjustments before moving forward with the project.

Design Change Management was designed for managing and propagating the design changes from the discipline where the change was made towards other disciplines. The one who needs to conduct the processes is usually the one who needs to maintain consistency in relevant disciplines. The main steps of this solution are to 1) review design changes from another discipline and 2) propagate the changes from another discipline. The scenario illustrates how the system facilitated the process of incorporating design changes to the door and staircase layout in a hall, extending towards the garage, by assisting the structural engineer in seamlessly propagating the modifications from the architectural model. This allows the engineer to focus on refining the design and ensuring its structural integrity, while also improving the overall efficiency and speed of the design process.

Clash Avoidance allows BIM users to detect and fix clashes with their own tools at their preferred frequencies. This empowers users to detect and address clashes at the earliest possible stage, without the need to wait for scheduled meetings or assignments. The main steps of this solution are to 1) detect the clash, 2) describe the clash, 3) propose solutions, and 4) authorise and apply a solution. The scenario depicts how the system automatically detected a clash between the sprinkler and structural opening, presented the issue to the relevant parties, proposed a solution to align their positions, and implemented the solution upon approval.



(a) *Detect the error* (b) *Describe the error*

(c) *Propose solutions* (d) *Apply a solution*

Figure 2: Error Correction

Error Correction considers the conventions, constraints and so on that cannot be detected as clashes when a design change has been made in another discipline. This function can be used at any time for checking and correcting non-spatial inconsistencies. In addition, it empowers the users to detect such errors at the earliest possible stage. The main steps of this solution are to 1) detect the error, 2) describe the error, 3) propose solutions, and 4) authorise and apply a solution, as shown in Figure 2. Specifically, this scenario demonstrates a convention in Nordic countries that the layout of the windows (shown grey) should be aligned with the layout of the radiators. However, following an interior design request, the window was split into two. Therefore, the radiator should also be split into two parts. This solution only has four steps but covers many features described in the paradigm concepts in the first section. As shown in Figure 2(a), integrated and interoperable, users can conduct different tasks without switching platforms; Figure 2 (b) (c) intelligent, the system is able to intelligently identify the inconsistencies of the conventions and propose corresponding solutions; Figure 2(d) automatic, apply the option proposed automatically at the object level. In addition, this solution contains the information management process, including propose, review, reject, approve, apply and so on.

Solution Testing

We conducted the third round of interviews with BIM users presenting these scenarios (the second round of interviews was conducted for the initial scenarios, which we will skip in this section). We conducted focus groups to probe in-depth questions, along with a minor portion of quantitative research in the in-interview survey, because this research mainly focuses on "if" and "how" this paradigm helps design change collaboration for BIM adopters, rather than the quantitative questions of "how often" and "how many."

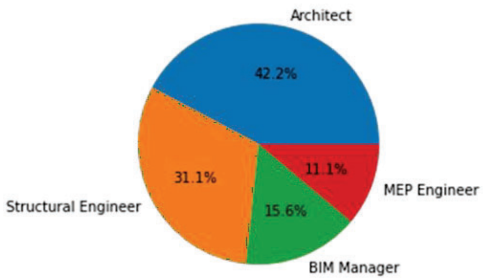
We conducted nine focus groups with 49 participants from more than 14 countries and regions. The interviewees were all BIM adopters: architects, structural engineers, MEP engineers and BIM managers. A qualitative research approach and a behavioural science approach were combined to design interview questions and protocols. In addition, participants were required to fill in the in-interview survey to quantify the effectiveness and efficiency of the proposed solutions. The sample information is shown in Figure 3.

Analysis and Discussion

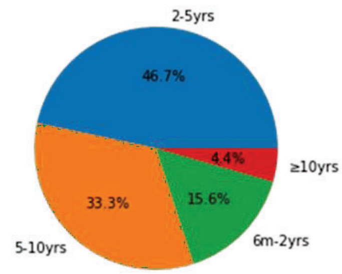
Inter-domain design change

Before digging into the analysis of each solution, it is important to understand how these interviewees comprehend the definition of inter-domain design change in our research context, and how important they think it is to improve the workflow and process of inter-domain design change.

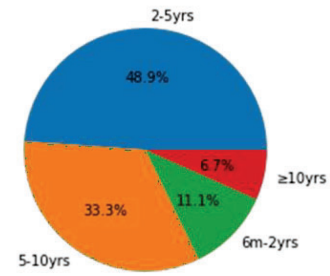
The result of the in-interview survey indicates that over 90% of interviewees agreed that inter-domain design change, if not well managed, can lead to rework, longer design duration, and increased project cost. However, only 82.2% agreed that it could decrease design accuracy. The reason for the lower agreement on this option is that



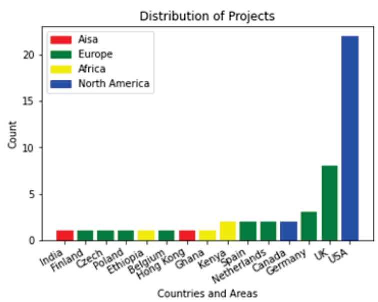
(a) Professional Distribution



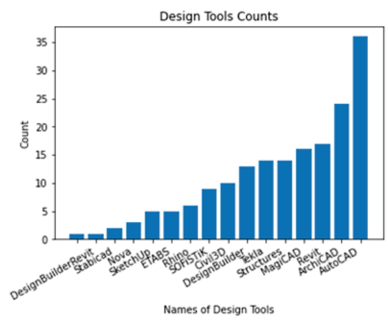
(b) Design Experience Distribution



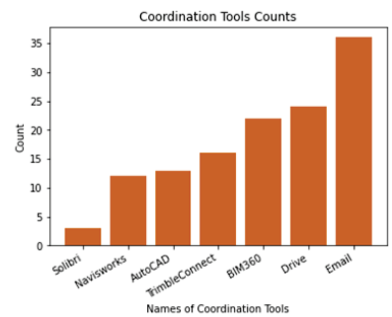
(c) BIM Experience Distribution



(d) Project Location Distribution



(e) Design Tools Distribution



(f) Coordination Tools Distribution

Figure 3: Sample Information

some interviewees believed that inter-domain design changes were necessary to improve client satisfaction and design quality. To clarify the question, we added "If not managed well," and interviewees agreed more with this option.

Over 80% of interviewees agreed on the importance of improving collaborative workflow and processes in inter-domain design change. They believed that current collaboration practices led to unsatisfactory outcomes and that improving workflow would minimize errors, increase efficiency, reduce rework, and avoid project delays. Interviewees also emphasized the need for better communication, more interactivity, and equal voice for all designers. Despite software tools' constant improvement, there has been little progress in ensuring good communication between them.

Interestingly, all interviewees acknowledged the importance of improving workflow and process in oral answers, but the survey revealed some disagreement. Some interviewees may not see workflow and process as significant factors in improving collaboration, beyond the natural distribution of opinions.

Elicitation of Use Case Scenarios

Each UI mockup of the four use case scenarios contains some features described in the paradigm in the introductory section. However, due to space limits, we only explain the main idea of each function in the Solution Development Section and elicit the initial insights from the interviewees for each specific function in this Section, skipping the detailed description of each scenario and solution. Afterwards, we discuss the general comments shared by all the scenarios.

Design Issue Avoidance

In general, around 87% of the interviewees held positive attitudes toward this function, considering it can “speed up the process of design modelling” (86.7%), “reduce rework” (84.4%), “shorten coordination time” (86.7%), “increase design quality” (90%).

The proponents supported the function because of the better collaborative method and consequences. Here are some of the supporting quotes: “it helps to identify which changes are necessary to make”, “the architect and the structural engineer collaborate very well in this scenario, there is no dispute”, “the way they collaborate is very efficient and proceeds effectively”, “it is necessary to have someone or a system to check my design all the time because we are human beings, no one is perfect”, “it can predict future clashes and have them corrected”, “I like that you can consult as you make a change with the design expert because it’s hard to get attention in real life.”

A few might have some reservations and wonder how this research can be technologically and commercially advanced. For example, “BCF is already more or less supporting this scenario although it’s quite a static thing, it doesn’t support the project-customised things you mentioned”, “consultant doesn’t sit there and wait for you to send a message”, “how can it happen?”

Design Change Management

In general, around 85.8% of the interviewees held positive attitudes toward this function, considering it can “speed up the process of design modelling” (86.7%), “reduce rework” (81.1%), “shorten coordination time” (81.1%), “increase design quality” (94.4%).

Several designers liked “the function of comparing the models before and after certain design changes and demonstrating the different portions exclusively because buildings are often very complex and it is very hard to find what has changed, what has been moving around in the model." In addition, some mentioned this automatic change propagation could definitely "reduce a lot of manual rework" and "makes life easier".

Compared with other solutions, this one was more complicated in terms of both workflow and functions. It might generate a lower percentage of acceptance from the interviewees. This is because some interviewees lost focus on the collaborative approach to the proposed solution, and argued instead that there were other possible alternatives.

Error Correction

In general, around 90% of the interviewees held positive attitudes toward this function, considering it can "speed up the process of design modelling" (88.9%), "reduce rework" (88.9%), "shorten coordination time" (88.9%), "increase design quality" (93.3%).

This function was well accepted not only because the scenario was simple, and the workflow was easy to understand but also because "it saves time and effort to automatically check non-geospatial overlapped errors". In addition, it can be applied to many similar cases, such as "the alignment of the toilets and pipes between architectural and MEP disciplines". Plus, "it is going to reduce the pressure in one direction or make sure the pressure is not extending to a particular direction because the information is shared, and people can interact to correct the errors".

Some interviewees commented that "it lacks some element of practicality" in this particular scenario, indicating that realistic factors like manufacturing need to be considered when certain elements of a building are ordered or prefabricated.

Clash Avoidance

In general, around 87.5% of the interviewees held positive attitudes toward this function, considering it can "speed up the process of design modelling" (83.3%), "reduce rework" (81.1%), "shorten coordination time" (88.9%), "increase design quality" (96.7%).

A major factor in achieving this high level of acceptance is that this solution is the most understandable among the four. In addition, several interviewees commented on the difference between this solution and the current clash detection method. Some said that this solution was better because "clashes can be detected without switching platform, at your preferred frequency and can be corrected automatically".

Different levels of concern were expressed by the experts regarding the clashes caused by the different sizes and functions of the building elements. This suggests that a future system should allow users to customise their rules for a specific project in the setting configuration.

General Comments

In addition to the comments on the specific solutions, there is some general feedback shared by all the scenarios.

An integrated and interoperable system is a common dream. However, we didn't make it obvious in the scenarios, only claiming that people can use their own tools for all the tasks. "I would love everybody to use the same format of design tools and messaging, but the reality is that we don't. Therefore, we have to send it via email, which is more universal, and it takes some time for all of the messages to come back and forth and such."

Automation was one of the most popular features discussed. "The part which I like most here is the tool can apply the proposed option automatically when the instructions are being given."

Trust was one of the main concerns of the interviewees. "Why would we trust this system?", "How would we trust each other in the construction project?"

Data is also an important aspect to build data-driven solutions. "To do so, you have to rely on data in making this design, so that the system can learn from experience and avoid some design issues."

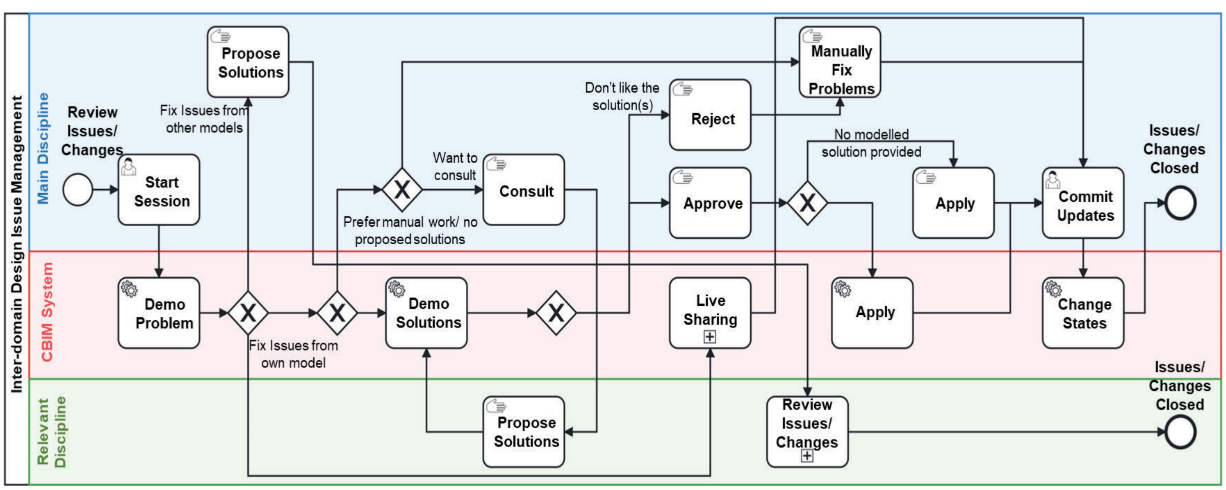


Figure 4: Inter-domain Issue Management BPMN Workflow

To conclude, in today's fast-paced and dynamic environment, people require a higher level of transparency, real-time updates, and personalised suggestions. They also need to have more interaction directly through models to understand the impact of their actions and decisions. At the same time, they value the freedom and flexibility to create designs and prioritise tasks at their own pace while protecting their ownership and intellectual property. Based on the analysis result, a Business Process Model and Notation (BPMN) workflow was conceptualised and modelled for inter-domain design issue management, as shown in Figure 4. This workflow outlines the activities involved in the issue management task and specifies who is responsible for each step, providing a comprehensive view of the entire process. By incorporating this workflow, organisations should be able to streamline their design issue management processes and optimise their resource allocation, leading to greater efficiency and productivity.

Conclusion and Future Work

Conclusion

This research applied the design science method to investigate how to drive a better collaboration in the detailed design phase, iterating between different activities and refining the understanding at each stage. Due to the limitations of space, this paper only briefly went through the main activities we conducted in Implementation Section, problem identification and solution development and testing, specifically, literature review, survey design and distribution, scenarios, and UI mock-ups design, focus group design and discussion. We briefly gave the descriptions and steps of four main solutions and demonstrated an instance of the Error Correction scenario, solution, and UI mock-up in the Solution Development Section. Afterwards, we conducted an initial elicitation of BIM-based interdisciplinary design change collaboration. Over 90% of interviewees considered that inter-domain design change plays a significant role in design collaboration during the detailed design phase. Over 80% of them agreed that it is important to improve the workflow and process of an inter-domain design change to better manage the collaboration. On average, over 85% of the interviewees held positive attitudes towards each of the proposed solutions, which reflect the concepts of the envisioned paradigm. Specifically, the experts claimed that these solutions provide more efficient and effective communication, an integrated platform allowing users to carry out different tasks, an intelligent agent offering automatic issue detection and correction, and an automatic review process to exchange and authorise design changes, etc. As a result, we can conclude that the proposed paradigm can theoretically enhance the efficiency and effectiveness of design cooperation and collaborative communication, as this has been acknowledged by many BIM experts.

4.1 Limitation and future work

First, the insights initially elicited from the interviewees may be incomplete, inconsistent, or even inaccurate, because the insights are influenced not only by the diversity of participants but also by the moderator's understanding of the topic, his or her skills, and how he or she conducts the focus groups. Each of these factors has been dynamically refined throughout the nine interviews over three weeks.

Additionally, this is an initial paper, and there is still much to be elaborated on and explored in the future. To begin with, the insights can be further analysed and categorised into requirements from various aspects, such as people, workflow & process, and technology. In addition, the proposed solutions can be further abstracted into workflow models for visualisation, simulation and. Furthermore, based on the workflow models, a simulation and an experiment can be conducted to evaluate the authenticity and accuracy of the workflow models.

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