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Influence of Digital Modality on Knowledge Transformation in BIM Design

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ABSTRACT

There is no clear understanding as to whether complex design problem-solving activities such as conceptualization, sketching, actions, transformation, and reasoning can be readily circumscribed into Building Information Modeling (BIM) design. This research investigates the phenomenon of collaborative design based on the BIM framework using the protocol study technique. The protocol consists of eight (8) multidisciplinary design teams who are subjected to the use of a digital modality (REVIT) to design a commercial kiosk. A coding scheme based on variables of knowledge transformation is employed to generate empirical data from the design protocols. A 4-point Likert scale was also used to validate the coded segments against the designers' actual intent. Statistical analysis using Chi-Square cross-tabulation has established a significant association between the digital modality (Revit) and the variables. The results indicate that the digital modality is statistically different concerning the distributed frequencies and duration of stages 1, 2 and 4 of knowledge transformation in BIM design. It was found that the BIM modality showed properties that may likely impede the high frequency and duration of personal experience, technical know-how, skills, views, vision, understanding, character, perception, morals and ideas among stakeholders. In conclusion, the study recommends the improvement of the BIM design to support socialisation, externalisation, internalisation, experiential and conceptual knowledge assets, originating 'ba' and dialoguing 'ba'.

KeywordS: BIM, Design, Knowledge transformation, Digital modality

INTRODUCTION

Grounded literature frames BIM design as a process supported by a software platform that will allow architects, engineers, and other construction stakeholders to work on one single virtual model. The model is embedded with multidimensional digital data for the production information of the building (Garber, 2023). However, this context of two or more people working together on a single digital model appears to be very basic, as it does not specify how the multiple design stages and their responsibilities can be transformed into a single explicit digital-based collaboration stage. This prompts the quest for this research.

LITERATURE REVIEW

This section presents a literature review on the concept of knowledge transformation and how it happens in BIM design.

The Concept of Knowledge Transformation

In the field of epistemology, knowledge transformation is the acquisition of a new understanding, a new view of the problem and a new solution. This is from being to becoming directly from individual cognitive instincts or behavior that are accumulated through experience, skills, training and

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learning (tacit) or directly from explicit materials such as books, drawings, artefacts, products, maps and documents (Nonaka et al., 2000; Prigogine, 1985; Polanyi, 1962; 1967; Nonaka, 1994). According to Nonaka et al. (2000), knowledge transformation happens among individuals (micro) and their immediate environment (macro) under three different milieux: the SECI process, "ba" the shared context and the knowledge assets. The three represent the context for knowledge transformation as originally established by Nishida (1921) and Shimuzu (1995). The context is a place where stakeholders interact and form the knowledge spiral, which represents the integrated social, cultural and historical basis for the interpretation of meaning and understanding among themselves. The context is not a physical space like an office, room or outside environment, but a medium formed by shared time, forms, and a virtual mental space where knowledge evolves and transforms. Therefore, the context is the place where the knowledge is evolving. A typical example of the knowledge transformation context is shown in Figure 1.

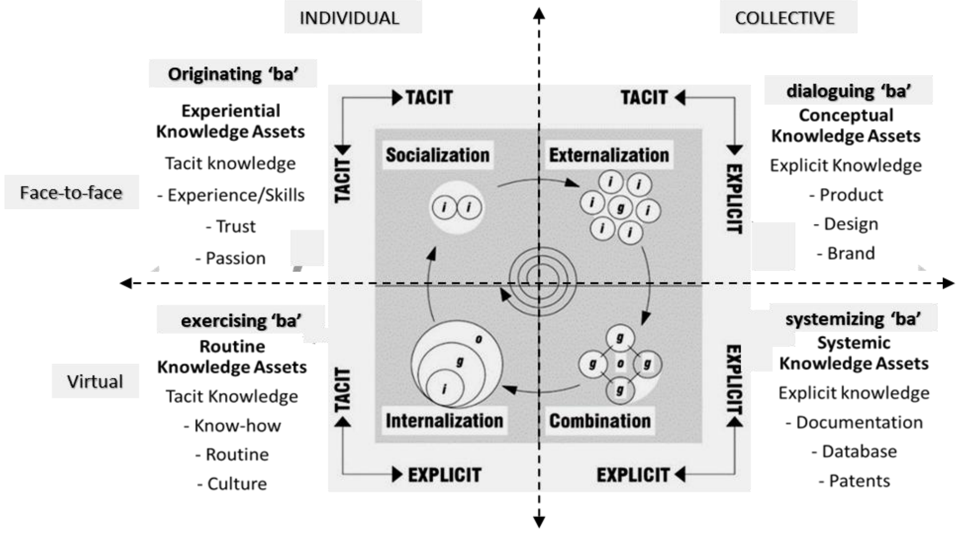

Figure 1: The transformation of knowledge (Nonaka et al. 2000, p.12)

Stage one; shown in the top left quadrant of Figure 1, is a knowledge transformation process through socialisation using face-to-face mediums (originating "ba") and experiential knowledge assets such as skills, know-how, experience, passion, trust, gestures and behavior. ***Stage two;*** illustrated in the top right quadrant of Fig. 1, is the second knowledge transformation process through externalisation, also using face-to-face mediums (dialoguing "ba") and conceptual knowledge assets like sketches, sounds, symbols, images, and language, which is the initial transformation from experiential knowledge assets to tangible conceptual information considered to be the basis of the product development. ***Stage three;*** In the bottom right quadrant of Fig. 1, the third knowledge transformation process is achieved through a combination of detailed model. This is done through modification, refinement, integration and upgrading, testing and implementation. This stage is specifically associated with using virtual medium to relatively improve and systematise with technology and other virtual mediums, such as using a virtual collaborative environment (the systemizing "ba"), with the help of systemic knowledge assets like specifications, detailed drawings and manual, tangible, and detailed information. ***Stage four;*** finally in the bottom left quadrant of Fig. 1, is the fourth knowledge transformation process through internalisation for generating new ideas using the virtual medium for sharing the properties of created explicit knowledge among individuals or organisations, such as virtual learning by doing, simulations, experiments, and reflection (exercising "ba"), as well as the routine knowledge assets.

Knowledge Transformation in BIM Design

Generally, the literature considers BIM design as a digital computer supported collaborative work (CSCW) for integrated project delivery (Idi and Khaidzir, 2018). Knowledge transformation in BIM design can be considered to be the process of transforming tacit ideas into explicit building products that can easily be seen, shared, and vice versa (Lin et al., 2006; Kasimu, 2014). Therefore, knowledge in BIM design can be considered to be a stage of intersection between tacit and explicit knowledge. A typical example of BIM design knowledge taxonomy is shown in Figure 2.

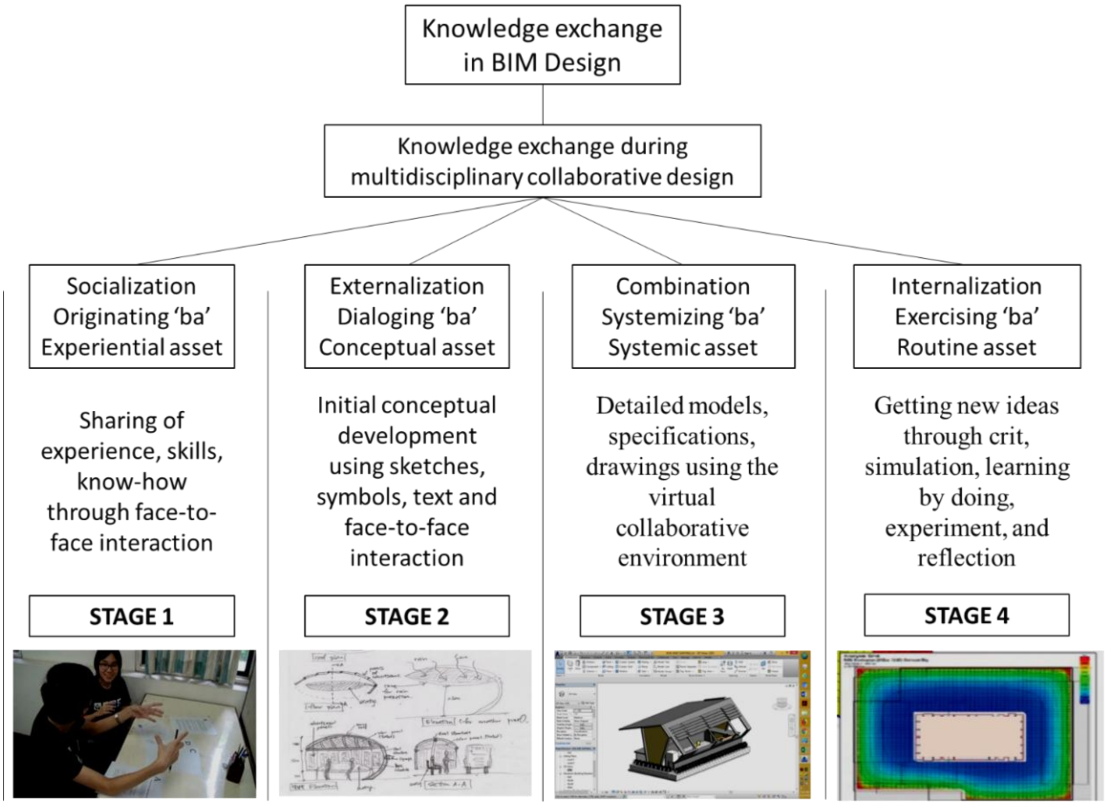

Figure 2: Knowledge transformation in BIM design

Stage 1

Stage 1 is the transformation of experience between individuals through face-to-face interaction, as demonstrated in Figure 2. According to Polanyi (1966), this is the transformation of human knowledge that cannot be exactly told about but can only be viewed through actions and verbal content. An example of stage 1 knowledge transformation in BIM design is the transformation of personal experience, knowledge, skills, views, vision, understanding, character, perception, morals and ideas among stakeholders through face-to-face interactions during collaborative design, as shown in Figure 3 (Sabherwal and Sabherwal, 2007; Nonaka, 1994). Stage 1 also represents the transformation of designers' technical know-how, skill rudiments, practical understandings, personal plans, mind maps, beliefs, viewpoints and stands that support their perspective on understanding and viewing situations. Typically, this type of knowledge is obtained through training, not theory. As a result, it is embodied in personal experience and available in unarticulated conscious awareness, such as rules of thumb, heuristics, and other 'tricks. Its nature made it a major research area among different disciplines such as architecture, psychology, and sociology.

Figure 3: Stage 1 of knowledge transformation in BIM design

Stage 2

Stage 2 of knowledge transformation in BIM design is the process of converting ideas, experience and skills into explicit knowledge that can be seen and understood by others, forming a starting point for the conceptualization process of product development and the explanation of product metaphors and analogies using the face-to-face medium. It is the space where designers document their experience so that it can be seen and understood. The major strategies used for stage 2 are symbols, images, and sketches as shown in Figure 4. This knowledge is the transfer of designers' experiential knowledge assets into tangible conceptual information considered to be the basis of product development. The conceptual knowledge assets are explicit in nature, which is less ambiguous when compared with the experiential knowledge assets. However, they remain the most influential factor in sustainable product design.

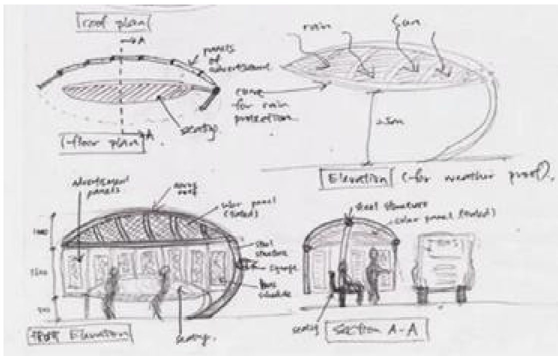

Figure 4: Stage 2 of knowledge transformation in BIM design

Stage 3

Stage 3 is the improvement of explicit knowledge into a detailed model or system of explicit knowledge. The process is carried out through editing, modifying, refining, integrating and upgrading sketches into detailed and precise newly formed knowledge, as shown in Figure. 5. The new knowledge can then be ready for testing and implementation. In this stage, computer supported technologies can be used to improve precision and accuracy. Systematising "ba" is a collective interaction using the virtual medium. It is the space where explicit knowledge is relatively improved and systematised using technology and other virtual mediums. The process is like a combination, using a virtual collaborative environment to systematise explicit knowledge into more detailed and complete explicit knowledge. Mostly, the systemizing "ba" facilitates the transfer of explicit to explicit knowledge. The systemic knowledge assets are also explicit in nature, but more detailed and clarified than the conceptual knowledge assets. However, they remain the most influential factor for sustainable product development and implementation. The systemic knowledge assets are finalised and finished detailed knowledge that has been adopted and recorded, such as specifications, detailed drawings, and manuals. They are the improvement and refinement of the conceptual knowledge assets into tangible, detailed information considered to be the manual of the product development and implementation process.

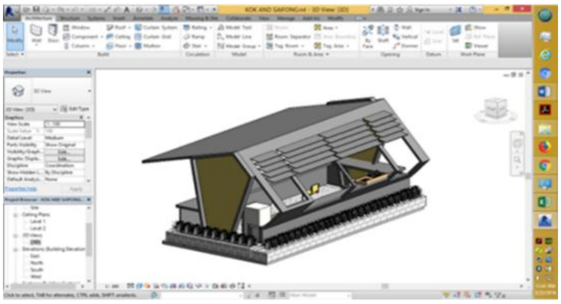

Figure 5: Stage 3 of knowledge transformation in BIM design

Stage 4

Stage 4 is the process of generating tacit knowledge from a completed finished product called explicit knowledge, as illustrated in Figure 6. In the process, the created explicit knowledge is shared among designers to generate new tacit knowledge out of the properties of the explicit knowledge. A typical example of internalisation includes learning by doing, simulations, experiments, and reflection. The process consists of the sharing of the explicit knowledge created among individuals or organisations to generate tacit knowledge out of the properties of the explicit knowledge in a virtual environment. A typical example includes virtual learning by doing, simulations, experiments and reflection.

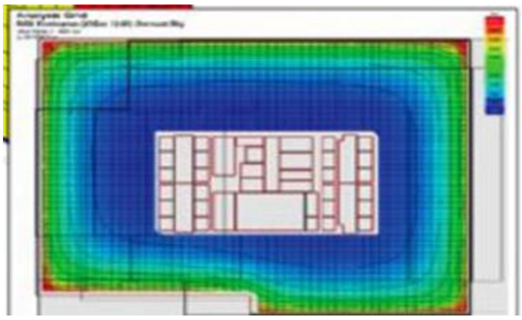

Figure 6: Stage 4 of knowledge transformation in BIM design

Thus, based on the preceding explanation and the literature review carried out so far, this research adopted stages 1 to 4 for the coding process of knowledge transformation. The four classifications are further explained in the next sub-sections.

MATERIALS AND METHODS

This section of the research describes the procedure for investigating collaboration in the context of design using grounded systems established by Snyder (1984); Saunders et al. (2015) and Groat and Wang (2013). As illustrated in Figure 7, the procedure for setting up the research method is categorised into three phases. Phase one is planning (philosophy, approach and design); phase 2 is technique (observation); and phase 3 is analysis (protocol analysis).

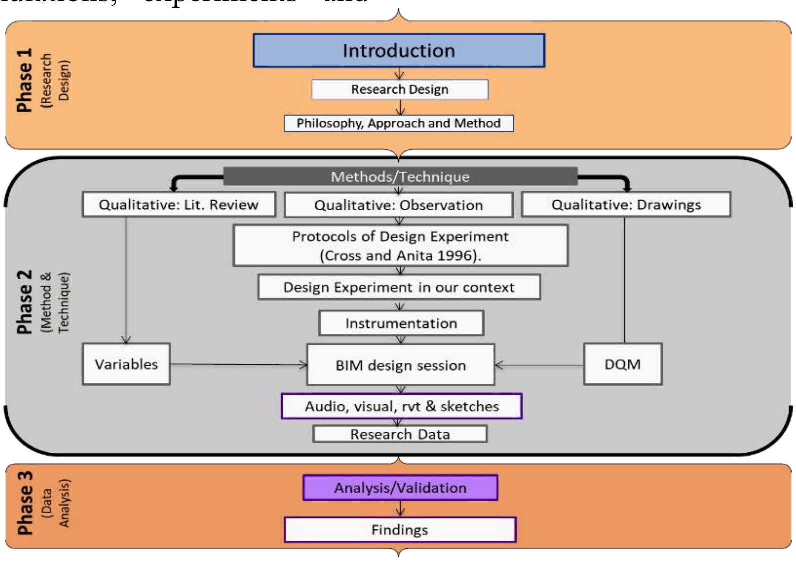

Figure 7: Research methodology

Phase 1 (Philosophy, Approach and Design)

The study adopted interpretivism philosophy, an abductive approach and a mixed method (Crotty, 1998; Sunders et al., 2015; Cassell and Johnson, 2006), as illustrated in Figure 8. The main purpose of selecting interpretivism as the research philosophy is its ability to create new, richer understandings, observations, analyses, interpretations and meanings of social interaction such as conversations, meetings and teamwork. The abductive approach was selected due to the fact that the literature does not provide all the variables that set the premises for the method, analysis, and conclusion; thus, abductive reasoning was adopted (Saunder et al., 2015; Suddaby, 2006; Van Maanen et al., 2007; Van Maanen et al., 2007). In this research, the mixed sequential method was selected. Specifically, the exploratory sequential mixed design, where text and frequencies of audio/visual observations were quantitatively analysed to establish the results, findings and discussions. As such, the weight of the mixing is more towards a qualitative than quantitative design.

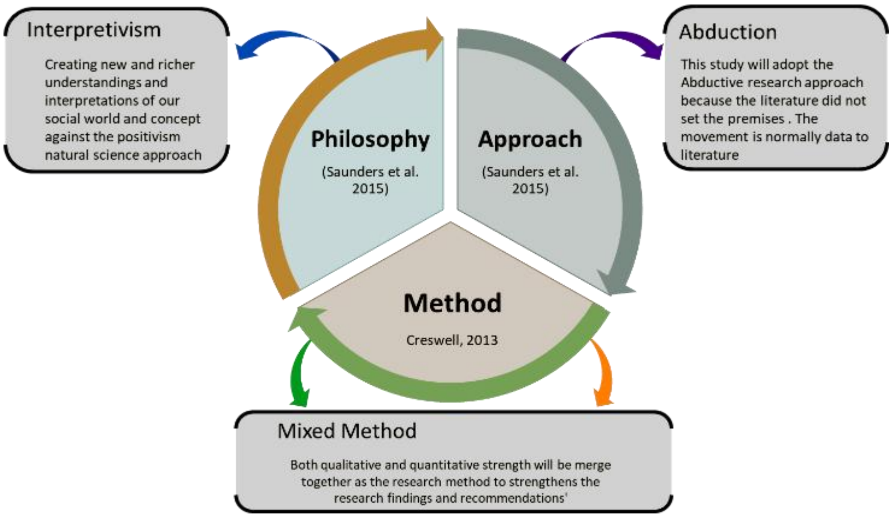

Figure 8: Research theoretical set-up

Phase 2 (Experimental technique)

The research technique is experimental. Dorst and Cross (2001) conducted the first comprehensive experimental strategy to study design. The experiment was an organised design session where designers were provided with all necessary design materials to solve a design problem, while the researcher or observer watched and recorded the audio and video of the design protocols. In this study, eight (8) different experiments by eight collaborative design teams of peer postgraduate designers from the Department of Architecture at Universiti Teknologi Malaysia during the 2015–2016 academic session were conducted, observed and recorded. The instrumentation provisions include mock-up sessions, 8 design teams, a design brief, computers, Revit software, sketching tools, audio/visual instruments, timers, studio rooms, three video camcorders, digital photo cameras, film editing, computer systems, stopwatches, bells, voice recorders, loudspeakers, drawing sheets and instruments, tables, and chairs. These instruments are technically arranged in the UTM Architecture Department Audio/Visual Lab, as spelled out by Dorst and Cross (2001). The teams worked collaboratively to solve the design brief presented on an A4 sheet of paper titled ‘A’. The brief was made the same in order to

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reduce the bias of the mental model (Khaidzir and Lawson 2013). All the teams work without the interference of the observer. Before the commencement of the experiment, everything was checked and made sure they were set appropriately according to the provisions, prescriptions, viewpoints and all other requirements spelled out in the literature.

The experimental procedure commenced with the appropriate distribution, positioning, and installation of instruments, spaces and mock-up sessions; the issuance of a design brief; design sessions; and subjects' interviews. A summary of the experimental set-up is presented in Figure 9. After the commencement of the experiment, a routine inspection of the instruments was conducted to ensure optimal records of conversation and visual data and also to avoid missing some valuable information. External sources of information like the internet, handphones, notepads, and books from third parties were strongly restricted to avoid influencing the originality of the conversational data.

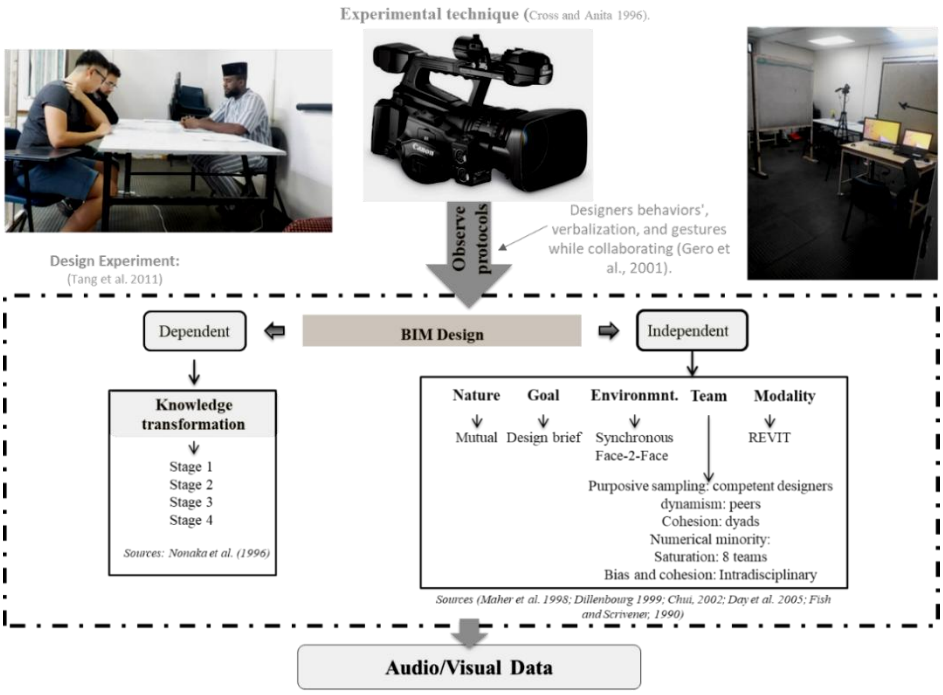

Figure 9: research experimental background, set-up and technique

Research Data

The research data obtained from the experiment are classified into A, B and C. Class A includes audio and visual records; the sketches are class B; and the rvt. files are class C. A detailed presentation of the three classes of data is shown in Table 1 and Figures. 10, 11 and 12.

Table 1: The Research experiment sessions

Teams	Session	Time (mins)
T1	1	24:00
T2	2	36:00
T3	3	40.08
T4	4	71:01
T5	5	39:50
T6	6	39:50
T7	7	50:18
T8	8	81:43

Figure 10: Class A (Audio-visual recordscollaborative design sessions)

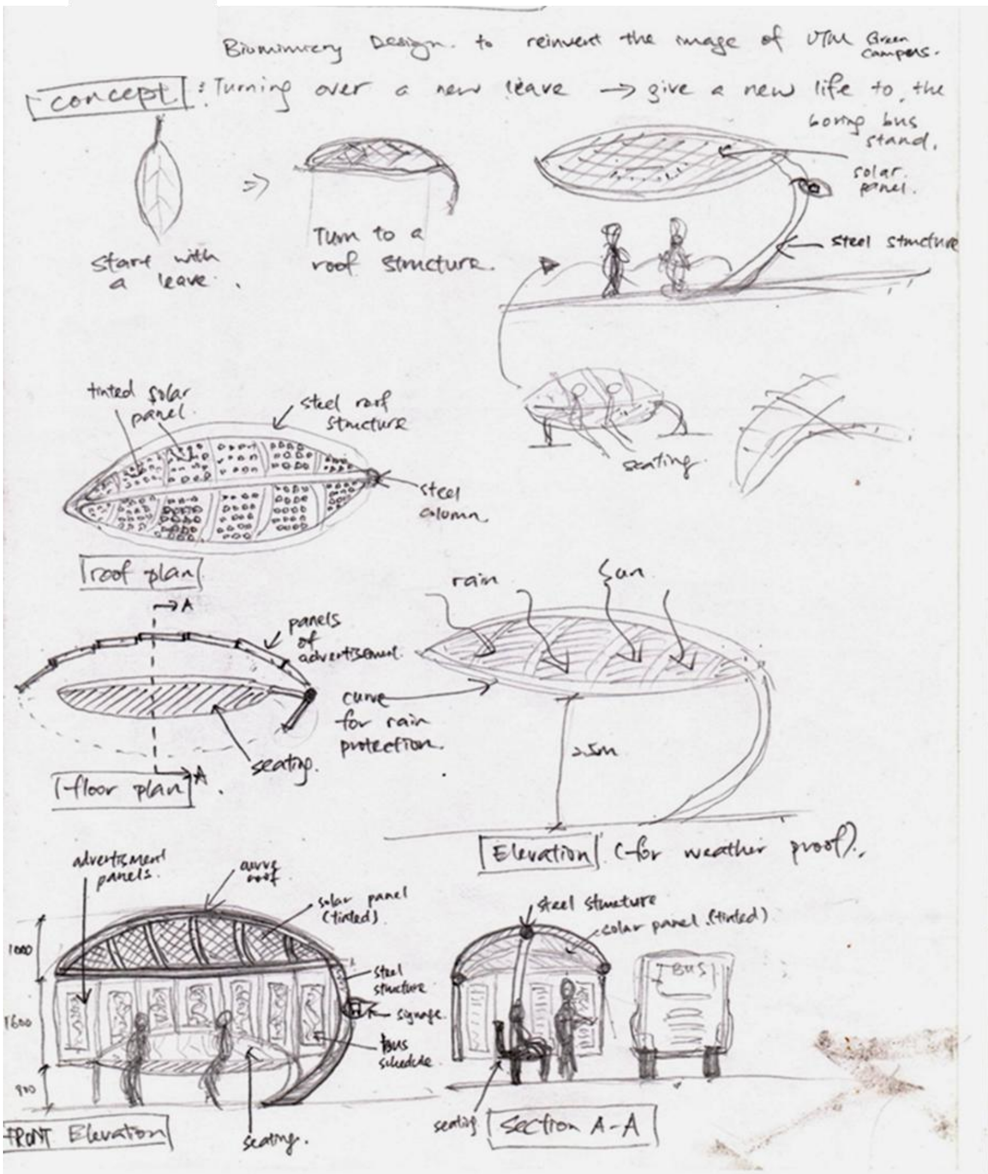

Figure 11: Data class B - sketches

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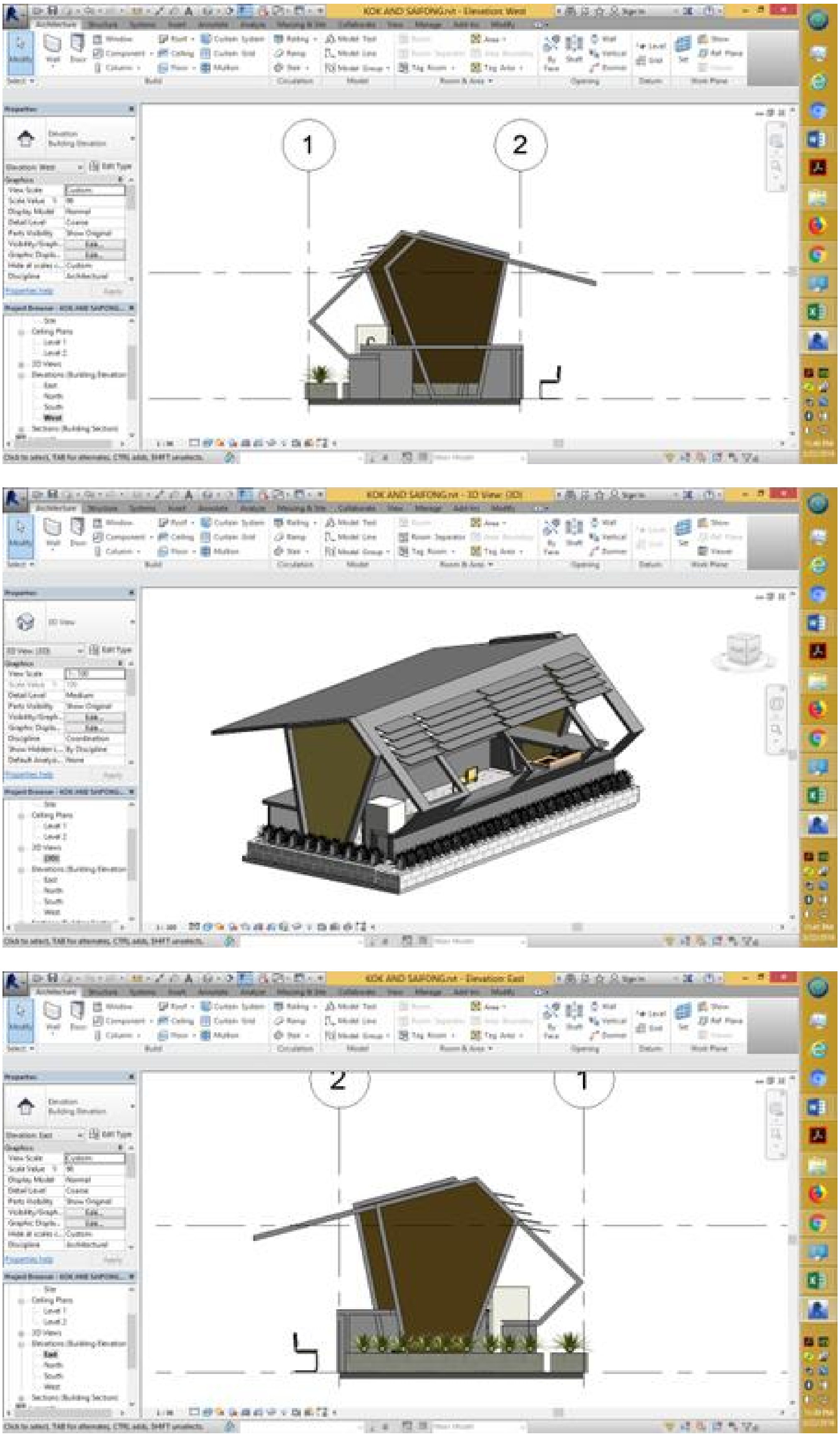

Figure 12: Data class C - rvt. files

Phase 3 (Retrospective protocol analysis)

The third and final phase of the methodology used in the study is the retrospective protocol analysis of collaborative design activities. This type of analysis is usually employed in order to observe the activities at a later time, which provides more opportunity to study the salient and ambiguous information that lies beneath the background of the designers' cognitive space. The analysis has sufficient provisions for uncovering the tacit characteristics of design thinking and problem-solving in design team activities. It is mostly regarded as the most suitable for the study of team practice (Valkenburg and Dorst, 1995). In the literature, there are two classifications and four strategies of retrospective protocol analysis, namely; microscopic and macroscopic, as well as content- and process-oriented protocols. However, for research investigations that are collaborative in nature, process-oriented and discourse analysis using measurable coding systems mainly from the fields of cognitive sciences, conventional studies, and linguistics are preferable due to their ability to penetrate complex multiple interactions from individual utterances and collective discussion (Gu et al., 2011; Dillenbourg et al., 1996; Erkert et al., 2000; Sonnenwald, 1996; Robillard et al., 1998; Robillard et al., 1998; Cross and Anita, 1996; Gero et al., 2001; Akin and Lin 1995; Tang et al., 2010; Maher and Tang 2003; Dorst and Dijkhuis 1995; Schon, 1983; 1984; 1987; 1991; Lloyd et al., 1995). Therefore, it can be seen that there is sufficient evidence that the retrospective protocol study has some sufficient evidence of uncovering the tacit characteristics of design thinking and problem-solving retrospectively.

VERBAL PROTOCOL ANALYSIS PROCEDURES

The audio-visual data are further transcribed, segmented, coded, analysed and statistically tested. Detailed descriptions are presented in Subsection 4.1.

Analysis Procedures (Transcribing, Segmentation, Coding, Validation, Tabulation And Statistical Examination)

The audio-visual data were transcribed into textual information, and further fragmented into segments of conversational 'pause' sentences that present a coherent proposition about an entity that is being designed' that has a complete meaning of what the observer is trying to identify from it, technically (Goldschmidt, 1991; 1995 & 2014). The segments are further coded using a literature-based coding matrix for timely processing (Velkemburg and Dorst, 2011; Suwa and Tversky, 1997; Goldschmidt and Weil, 1998; Suwa et al., 1998; 2001; Khaidzir and Lawson, 2013; Helmi and Khaidzir, 2016). Examples of transcription, segmentation and coding are shown in Figure 13.

All the coded segments are further validated to make sure they represent their actual mental models of the designers, which is the "degree of match" between the utterances and the message they meant to convey (although what constitutes a "good enough match" is often unclear). A 4-point Likert scale was used to balance the opinion of designers against the meaning of the coded segments and to provide some guarantee against any bias or misinterpretation of the designers' actual intent (sample shown in Figure 13). That is, if the meaning of the coding fits the mental model of the designers that was derived from the segments, then one can predict that one's answers to certain questions will be consistent with that mental model. 85% of the 16 respondents strongly agreed, while 9% disagreed. The respondents have shown a high rate of agreement, which is an indication of the acceptability of the segmentation and coding.

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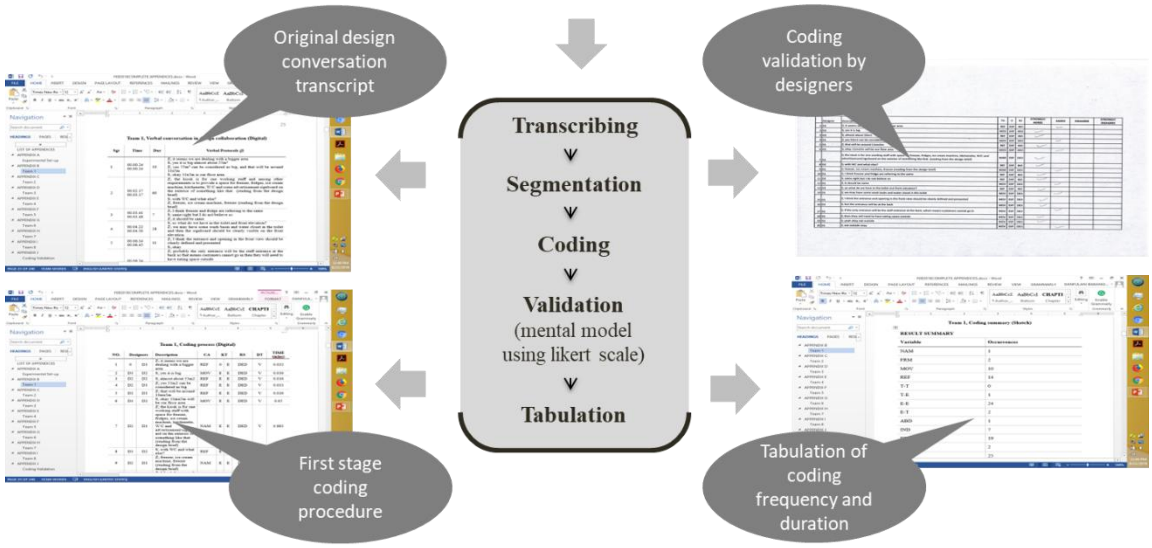

Figure 13: Process of transcribing, segmentation, coding, validation, tabulation and statistical examination

The outcomes from the coding sheets are quantities of frequencies and time durations for the coded segments, as presented in Table 2. The dependent and independent variables are presented in the columns, i.e., stage 1 to stage 4. The rows contained the frequencies and time durations of the variables distributed according to the design teams (T1 to T8).

The SPSS non-parametric statistical test was selected and used specifically the Chi-square and Spearman's rho correlation tests due to their abilities to handle small sample sizes, approximately less than 30 samples, and are in most cases suitable for case study research (Creswell, 2012; Pallant, 2001; Hoskin, 2012) to establish the influence of digital modalities on knowledge transformation in BIM design.

Table 2: Tabulation

Frequencies				
Teams	Stage 1	Stage 2	Stage 3	Stage 4
1	0	0	35	0
2	0	2	29	3
3	0	7	110	8
4	0	0	60	0
5	0	2	43	3
6	1	1	49	3
7	1	5	63	4
8	0	3	149	3
Total	2	20	538	24
Duration (mins)				
Teams	Stage 1	Stage 2	Stage 3	Stage 4
1	0	0	3.0	0
2	0	0.2	11	1.5
3	0	0.6	24	1.0
4	0	0	14	0
5	0	0.7	6.5	0.5
6	0.1	0.1	9.8	0.7
7	0.3	1.5	14.7	1.2
8	0	0.8	34	0.3
Total	0.4	4.0	119	5.5

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RESULTS AND DISCUSSION

This section presents the results and discussion on the influence of digital modality on knowledge transformation in BIM design. The Chi-Square two-way cross-tabulation analysis has established that stages of knowledge transformation can be influenced by the digital modality in BIM design as shown in Table 3. Statistically, the influence was found to be a very significant association at the level of x2 = 1202.000a, df = 3, and p =.000. The implication of the results means that the digital modality yielded significantly varying frequencies and durations of stage 1, stage 2, stage 3 and stage 4 can be seen in Figures. 14 and 15.

Table 3: The Chi-square Result Output

Chi-square Test			
Output	Value (x2)	Degree of freedom (df)	Significance (p)
Digital vs Stage 1, 2 and 4	x2 = 95.961a	3	p = .000

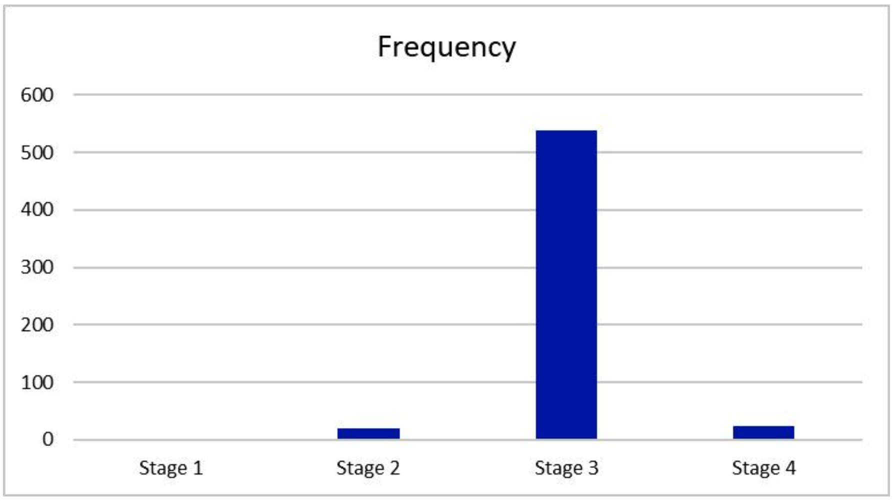

Figure 14: Frequency of knowlegde transformation in BIM design.

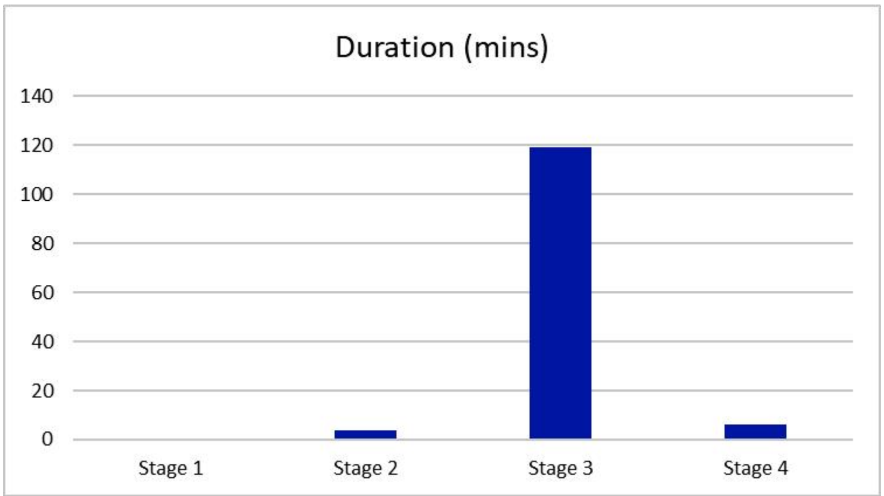

Figure 15: Duration of knowledge transformation in BIM design.

Conversely, this means that designers don’t adequately carry out the following functions when using digital modes in BIM design: 1. Evaluation of abstract ideas and concepts; 2. Accessing experiential and conceptual knowledge assets, and 3. Using originating and dialoguing "ba's.”. This further indicates that the digital modality elicits a very low frequency and duration of socialisation, externalisation, and internalisation, which revealed that designers seldom share, discuss, interact, externalise, and generate and transform new design knowledge when using the digital modality. This affirmed that the digital modality might not be a proper dialectic tool capable of tacit-tacit, tacit-explicit, and explicit-tacit transformation in BIM design. The results additionally indicate that the digital modality also impedes fundamental and core design problem-solving intellectual assets and spaces (experiential and conceptual knowledge assets and originating and dialoguing ba's) that support creative and innovative concepts emanating from visual reasoning that dissimilate widening idea exploration possibilities.

Henceforth, this study strongly recommends and suggests that there is a need to improve the digital modality so that it can adequately prompt socialisation, externalisation, and internalisation, as well as experiential and conceptual knowledge assets and originating and dialoguing ba's (see Fig. 1).

Consequentially, while investigating BIM in academia, Agirbas (2020) found that BIM collaboration supports teaching construction sciences among undergraduate architecture students. This finding postulates great concern as computation-based approaches in design have rapidly become popular among architects and other designers, as highlighted by Caetano et al. (2020); Okakpu et al. (2019); and Idi and Khaidzir (2018). The findings also concur with Ramilo and Embi (2014), Castelo-Branco et al. (2022), Oosterhuis (2012), and Majzoub et al. (2023) on the grounds that there exist in-depth technological, financial, organisational, governmental, psychological, and process barriers encountered in the adoption of digital innovation.

CONCLUSION

Finally, this article establishes that knowledge transformation is influenced by the digital modality in BIM design. Consequently, the article outlines the following conclusions:

1. There is a need to improve the digital modality so that it can adequately prompt socialisation, externalisation, and internalisation, experiential and conceptual knowledge assets, and originating and dialoguing ba's.
2. The digital modality impedes high frequencies and time durations of tacit knowledge transformation in BIM design.
3. This article has established that when using the digital modality, designers' ability to use the channels of tacit knowledge transformation is negligible.
4. Even though contemporary framework conditions adopt BIM design as the main building construction game-changer, it lacks adequate support and opportunity for socialisation, externalisation, and internalization. Thus, there is a need for improvement in the effective access and application of tacit knowledge problem-solving space in the BIM framework of design collaboration.

Based on the above outlined conclusions, the study does hereby recommend the full improvement of digital modalities in the BIM design to support socialisation, externalisation, and internalisation, experiential and conceptual knowledge assets, and originating and dialoguing ba's.

LIMITATION

Complexity, dynamism, bias, free riding, numerical minority, and self-disclosure in teams limit the study to peers of competent designers. Difficulty handling tacit knowledge variables like emotions, facial expressions and body-language are consequently excluded. Due to resources, cultural influence, and system limitations, the study was limited to the available facilities in the department of architecture BIM lab, UTM Malaysia.

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