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SOCIAL BIM: CO-CREATION WITH SHARED SITUATIONAL AWARENESS

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SUMMARY: *A common data environment (CDE) is a specific requirement for Level 2 BIM in the UK in accordance with BS1192-2007 and PAS1192-2 standards. It is a central repository of BIM data and examples include 4BIM and Autodesk 360. These repositories have some disadvantages:(i) it is after synchronisation or file upload that changes between local and cloud versions of BIM models can be appreciated by remote teams; (ii) there is a cost associated with subscribing to these servers, which could marginalise SMEs wanting to adopt BIM; and (iii) during the design phase, these systems do not permit real-time co-creation capabilities or audio-visual consensus amongst designers. So although these repositories are helpful technologies, it is people who collaborate (not systems) and in the design phase, audio-visual feedback and consensus can augment the collaboration experience and outcomes. With socio-technical input, the quality of BIM data/models generated by team members can be enhanced (and clashes minimised) if visual isolation is eliminated.*

This research presents a framework and proof-of-concept which redefines Social BIM (SBIM) as a socio-technical mode of BIM that enriches the co-creation process for Levels 2 and 3 BIM. It enables 'shared situational awareness' by empowering remote participants with visual and remote control of BIM models using GoToMeeting as a 'groupware'. The BIM data was hosted by surrogate servers linked to cloud-based storage. A quasi-experiment through a desktop sharing and communication system enabled 14 globally dispersed participants to control the graphical user interface (GUI) of a host PC in the UK running Autodesk Revit. Four audio-visual collaboration protocols were developed and three were tested. Participants interacted via the host PC remotely using computers (which acted as nomadic servers) and with mobile devices. Remote desktop/laptop users had unlimited control of the data in host PC, while real-time audio-visual communication improved the collaboration and co-creation of 3D BIM models. The experience of participants in editing BIM models was a function of internet bandwidth, hardware and operating systems. Unitary optimisation of modelling efforts/outcomes was possible on shared/coordination models. Divisible optimisation of industry-specific tasks (i.e. architectural, engineering and management) by participants was enhanced by feedback which was either on-demand (requested) or just-in-time (spontaneous).

KEYWORDS: *Social BIM, desktop sharing, real-time collaboration, BIM maturity, shared situational awareness, surrogate server, Level 2 BIM.*

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1. BACKGROUND

Building information modelling (BIM) is a process driven by revolutionary authoring and sharing technologies (Hardin, 2009). Though it aids collaboration amongst professionals in the architecture, engineering and construction (AEC) industry, merely utilising dedicated BIM technologies by participants in a building project may not guarantee that collaboration is taking place or that such collaboration has been optimised. It is people (not systems) that collaborate. Hence, optimisation of human efforts and resources would be critical for Levels 2 and 3 BIM, where it is postulated that designers should aggregate or produce a single BIM model in a central, integrated or federated location (Figure 1). The need for AEC professionals to have concurrent access to a building model without compromising the integrity of the model was pointed out as far back as Eastman and Jeng (1999). Yet it has been argued (Shafiq et al., 2012) that BIM technology has not presently delivered the desired requirements for collaboration in the AEC industry, and as a result, they proposed a model server as a form of collaboration platform. Leading developers of dedicated BIM software have developed features within their applications to assist communication and collaboration with the support of in-house and third party cloud-based servers.

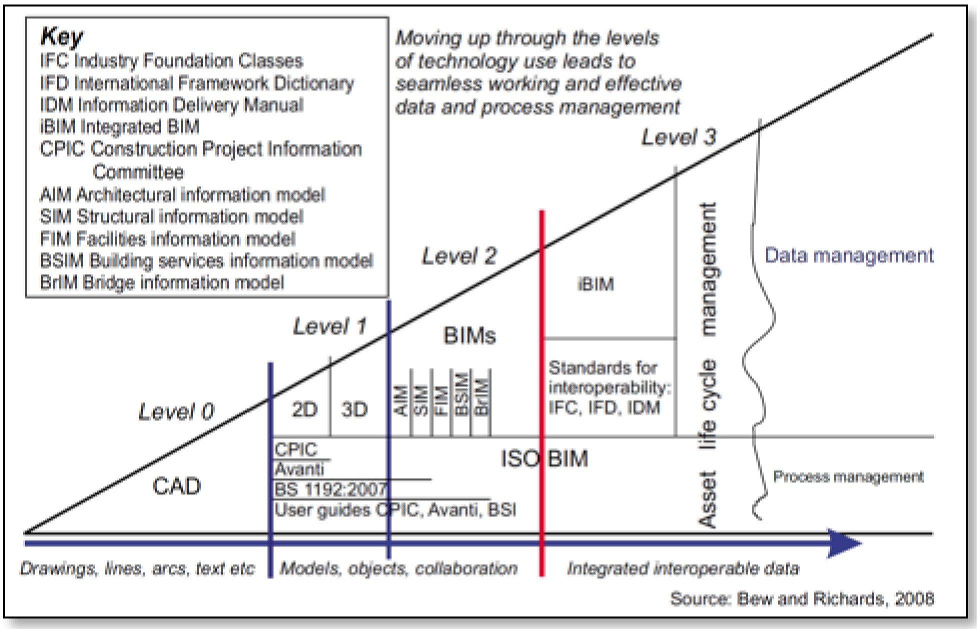

FIG 1: The BIM Maturity Diagram (Bew and Richards, 2008[1])

However, while BIM technology can be interactive and intuitive, it has been observed that in educational AEC settings, some students get carried away by the technology to the detriment of actual learning – or collaboration (Peterson et al. 2011 and Poerschke et al. 2010). The extent to which this applies in professional development settings is not clear from existing literature, but the same professional tasks associated with collaborative BIM modelling (Shafiq et al. 2013) do manifest in the form of role playing by students (e.g. Becerik-Gerber et al. 2012). Besides, students represent the next generation of professionals who can bring new skills (or bad habits) to industry and Fioravanti (2008) had argued that in their education, the deficiencies of multi-disciplinary collaboration as well as the scarcity of appropriate collaboration tools need to be addressed. There are examples of studies (Iorio, et al. 2011; Plume and Mitchell, 2007; Leicht, et al. 2009) which have attempted to address this challenge.

For AEC collaboration, real-time multi-media communication has been found to be useful for geographically dispersed design teams. This is frequently supported by teleconferencing systems including popular platforms

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[1] *Source: http://mosaicprojects.files.wordpress.com/2012/06/bim-uk.png*

like Skype, Adobe Connect and GoToMeeting (GTM). A study by Becerik-Gerber et al. (2012) revealed potentials and problems with remote collaboration involving of two sets of undergraduate students from two bicoastal universities in the USA. There was no evidence of real-time joint BIM model development with participatory real-time feedback on the design process amongst the students. Some teams relied on specific individuals who were better skilled in 3D BIM modelling while others complained of not knowing the level of progress in other member's models. Just as in Kovacic, et al. (2013), students also complained about the workload and scope of project (Becerik-Gerber et al. 2012), and these might have been alleviated if tasks (e.g. the model creation process) were divided and executed in a participatory manner in real-time. The challenges of isolated designing may have been relieved with shared situational awareness, which according to Cannon-Bowers, et al. (1995) is central to team effort. Excessive workload may have been lessened by adopting principles of divisible and unitary optimisations (Steiner, 1972). It could be argued, therefore, that the lack shared situational awareness and optimum task delegation had deprived the students (in Becerik-Gerber et al., 2012) of an enhanced learning and collaborative experience.

Situational awareness is a relatively new theory defined by Endsley (1995a) as the capacity to perceive and comprehend features of an environment (people, actions, events and information) while bounded by a volume of time and space and being able to grasp near future status of a task or project (Figure 2). The situational awareness theory is beneficial in explaining dynamic decision making processes and BIM (as a process) has all the intentions and attributes of such dynamism. In fact, situational awareness can be deduced to be a necessity amongst team members and can be a key advantage (if not objective) of the BIM processes, during which collaborating parties depend on jointly produced data and information.

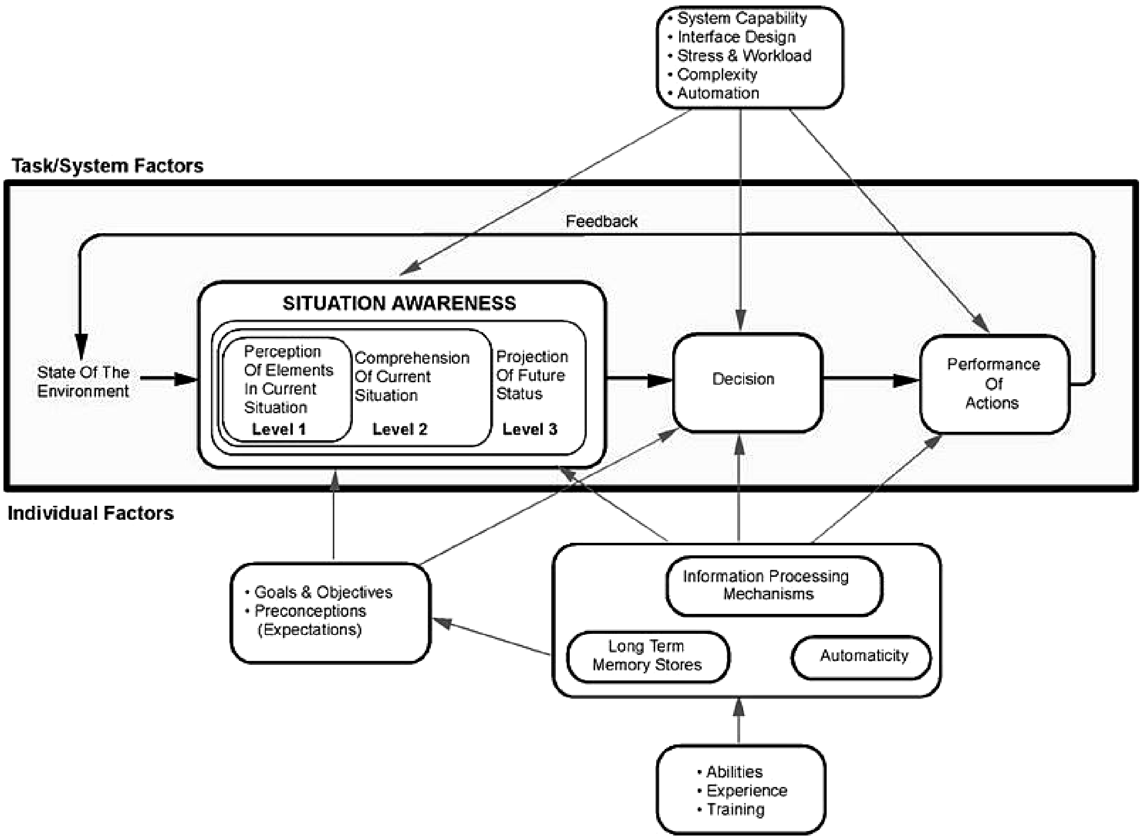

FIG 2: Situational awareness in dynamic decision making process (Endsley, 1995b)

Unfortunately, situational awareness is a theme that is largely untouched in BIM research except for few ancillary examples like Ranat et al. (2012). Ideally, situational awareness also needs to be 'shared' by all team members for effectiveness and many examples can be found in research (Saner, et al. 2010; Saner, et al. 2009; Nofi, 2000 and Cannon-bowers, et al. 1995) where '*shared situational awareness*' is described. The BIM domain, though powered by technology and potentials for real-time communication, is currently lagging behind in utilising the concept of shared situational awareness with respect to BIM technology and processes. Nevertheless, virtual collaboration and interaction in the building design process appears to have developed in the AEC industry along two main streams: as learning and teaching tools/processes; and as an industry-based approach to integrated design. The virtual design studios (VDS) concept was defined by Maher, et al. (2000) and has recently evolved into virtual design studio within social network (SNVDS) (Schnabel and Ham, 2012). This approach points to interesting potential of remote multimedia communications in a *socially-engaging*, virtual teaching and learning environment. Though these social-engagement concepts are aimed/tested primarily at educational settings, this sector is best placed to prepare a new generation of AEC professionals who are not 'selfish collaborators' (Fioravanti, 2008).

In another example of collaborative working in educational setting, architectural technology students of the Dublin Institute of Technology were tasked with developing a refurbished design for an existing building (Mathews 2013). Students created a master BIM model which was then sub-divided into sub-models or work-sets (i.e. elements of building such as external walls, floors, internal walls and stair core). The modelling of these elements became the responsibility of specific members. The advanced modelling skills of a specific team member were relied upon for the master BIM model and others synchronised their sub-models with the master model. They also had to *communicate each synchronisation* event to other members. This was done through instant communication that often led to discussions about design decisions. There was no real-time co-creation or remote control of computers, which is understandable since all members were co-located. Yet, the group often struggled to locate sketches scattered on the table at the conceptual stage of design (Mathews (2013). It can nevertheless, be inferred that this group of collaborators experienced *shared situational awareness* collectively, since all participants were physically co-located. For remote participants, however, using multiple communication channels *simultaneously* is central to successful virtual collaboration (Sher et al. 2009). The challenge (as this study intends to address) is how to equip geographically dispersed teams with processes and tools that would allow multiple formats of communication, interaction and shared situational awareness for co-creation of virtual buildings. The enablers for overcoming this challenge include: cloud computing; optimisation of group efforts and task delegation; as well as socially-inclusive collaboration protocols. These enablers are reviewed in the next sections.

2. CLOUD COMPUTING AND BIM TECHNOLOGIES

The underlying and defining principle of cloud-based computing is the availability of shared resources in a pool, essentially guaranteeing concurrent access to stored files, applications and services within a network or in a server (Mell and Grance, 2011). The successful deployment of cloud-based BIM systems depends on two factors which are: the level of accessibility of BIM models (which could be real-time concurrent, lightweight or offline); as well as performance of computing systems, which depends on hardware (Wu and Issa, 2012). So far, evidence in literature suggests that cloud-based BIM applications are largely based on dedicated servers (Shafiq, et al, 2013) or apps that are specifically designed for some market leading BIM software or device manufacturers (Khemlani, 2011). The generic types, platform and functionalities of relevant apps have been summarised in Wu and Issa (2012) where it was obvious that by definition/function, such apps (with the exception of AutoCAD WS) are hardly able to offer full editing capabilities. They are mostly model viewing tools for project management and document sharing aimed at leading BIM applications including Graphisoft's ArchiCAD and Autodesk's Revit.

Wong, et al (2014) and Mahamadu et al. (2013) found that use of cloud-based technology for BIM projects has several challenges in data management including responsibility, ownership and liability of cloud-based models. Based on extensive feedback from industry consultations, Beach, et al. (2013) developed a prototype cloud-based a data sharing solution that provides a governance model for BIM data. This was deployed through CometCloud engine which provides a secure and scalable storage and retrieval of building data. There is also a need for considering web-based operating systems and hardware that would support 'big data' for which both upload and download speeds of large files and datasets is critical (Yoders, 2014). In addition, there is a lack of education/training on using cloud-based systems (Wong, et al. 2014) while McGraw-Hill Construction (2014) have identified moderate to high levels of security concerns over the use of cloud technology for BIM data.

2.1 Generic BIM servers

IFC-compliant model servers that host data and information for BIM models (Jorgensen, et al. 2008) have been characterised by Shafiq, et al (2013) as model collaboration systems (MCS). Autodesk's Revit Server (Khemlani, 2010) is an example of MCS, albeit, optimised to work with native Revit files and not IFCs. Through this server, it is possible for centralised (shared) utilisation of Revit files, which can be downloaded. Designers would work on local copies before they are synchronised with the server (Figure 3). Such dedicated BIM servers can be used throughout the lifecycle of a building: from virtual conception to facility management with specific technical, legal, contractual, administrative and user-support requirements (Singh, et al. 2011). Autodesk 360 is an emerging variant of Autodesk Server whose capabilities are offered through software-as-a-service (SaaS). Subscribing customers or team members can create, share, store and retrieve BIM data using SaaS technology (Autodesk, 2012).

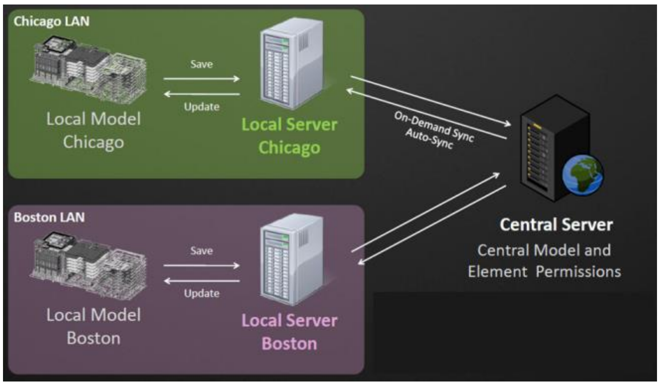

FIG 3: Revit server system with central and local servers with their models (Khemlani, 2010)

Three possible collaboration scenarios (Figure 4) are possible with MCS: collaborating through separate BIM models; collaborating through separate BIM models with an aggregated model; and collaborating through one shared BIM model (Jorgensen, et al. 2008). Although useful for Level 2 and Level 3 BIM, the shared BIM model scenario (Figure 4c) will be sub-optimal if real-time concurrent model development (i.e. co-creation) does not occur among designers. In other words, designers using this scenario may experience *situational awareness* (i.e. comprehension or knowledge of overall project progress). However, if they are to be bounded by same volume of time and space in order to grasp near future status of tasks, *shared situational awareness* is necessary. This can be achieved by real-time co-creation, devoid of audio-visual isolation.

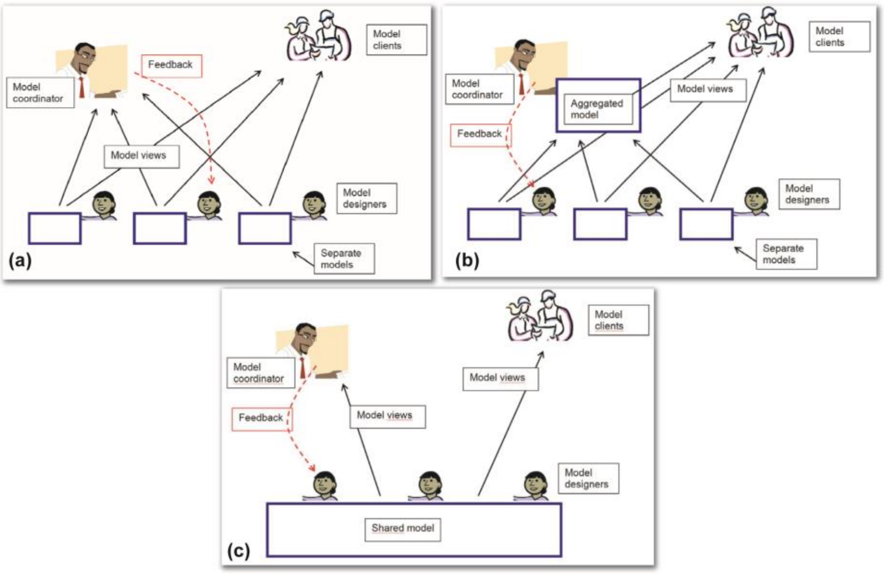

FIG 4: Model collaboration systems showing scenarios for (a) separate BIM models, (b) separate BIM models with aggregated model and (c) shared BIM models (Source: Jorgensen, et al. 2008)

2.2 Adoption of BIM Technology and SMEs in the UK

According to the SME BIM Feedback Report (Open BIM Network, 2014), one of the key concerns and barriers of adoption to BIM by SMEs operating in the UK is the associated cost of setting up the multiple technologies often required to build BIM capacity and to utilise digital workflow process. Bryde, et al. (2013) also argued that intensive cost-benefit analysis of BIM is required in order for organisations to rationalise initial investment into the technologies and procedural changes. Data collected from the 'BIM-readiness' survey indicates that: only about a quarter of SMEs in the UK construction sector had experience in parametric modelling; 24% of SMEs do not see any business opportunity in BIM; and only 10% had any plans to invest in training (NFB, 2012). A study by Rezgui, et al. (2013) showed that although SMEs dominate the construction phase in the UK, their technical maturity and process capabilities are limited. Consequently, unless they adapt early enough to meet the government's targets and specifications BIM adoption will be a threat to their businesses. What these studies suggest is that cost of deploying and utilising BIM technology is an important factor for UK SMEs. This issue will be addressed in this research by demonstrating alternative and cost-effective solutions to collaboration technologies.

2.3 Common Data Environment (CDE)

A CDE has four kinds of folders or document containers: Work-In-Progress (WIP), Shared, Published and Archived. The WIP folders are containers models that are 'unverified' and 'used by in-house design team only' (Figure 5). Each discipline has its own WIP folder and according to specifications of BS1192-2007 (BSI, 2007) and PAS1192-2 (BSI, 2013), a structural designer is expected to fetch the architectural model from the 'Shared' folder before carrying out structural modelling (Figure 5); the MEP designer will come in much later. The input of structural and MEP engineers is somewhat fait accompli, (i.e. after the fact). Such engineers are only able to contribute to the model development after architectural decisions have been finalised and made available in the 'Shared' folder. The sequestered (unverified) nature of the WIP phase implies, therefore, that many key decisions could be taken in isolation. In fact, research has shown that the causes of clashes in BIM include uncertainty and lack of clarity about other systems (Tommelein and Gholami, 2012) as well as the pursuit of speciality objectives in isolation (Plume and Mitchell, 2007). Also, the iterative nature of data sharing could prolong the design cycle in multi-disciplinary teams (Flager and Haymaker, 2007). In cloud-based CDEs and MCS, model harmonisation and synchronisation (e.g. comparing different versions of model) is a necessary feature to manage changes before consolidation (Shafiq, et al. 2013). Change management can also be done through notifications and communications to the central model from each working (local) model, as well as Archiving (BSI, 2007). Model-merging whereby different parts of a model developed in local systems are fused into one consolidated version is common in CDEs like 4BIM/4Projects (OpenBIM, 2015), often for the purpose of clash detection. Yet, merging is necessary due to the *fragmentation of the model creation processes* according to disciplines, even though all efforts are geared towards one end product.

So whereas cloud-based MCS and CDEs enable viewing, sharing and downloading of BIM models, the lack of online co-creation means there is partial digitisation of the 'silo' design process, especially in the WIP phase. Consider that on actual construction sites, the assembly of architectural, structural and mechanical systems of a building occurs concurrently (with overlaps). The AEC industry needs to mimic this construction site process for joint development of virtual models by embracing shared situational awareness and co-creation. This would require joint commitment from software developers and practitioners, with repercussions on how future designers are trained. It would be better if current CDEs are able to permit more 'groupware' functionalities (Ellis, et al. 1991) during design but remote desktop services, e.g. GoToMeeting (Citrix 2013a) which enable keyboard and mouse control can be used for real-time distributed groupware.

Other limitations that traditional cloud-based MCS impose on collaboration border on the efficiency and effectiveness of workflow. Using MCS such as Revit Server has implications for downloading (and local reuse) of very large files in the central server (Khemlani, (2010) and without fast bandwidth, the process of retrieval, content creation and synchronisation can be slow. This bandwidth issue is confirmed by the lead author's experience in teaching 4BIM to undergraduate students. Additionally, editing or updating of 3D BIM models requires synchronisation to the CDE/MCS, and design changes often occur without the 'audio-visual' consent, approval or understanding of remote team members. This could have ramifications for quality of socio-cultural input which can influence the resulting technical end product (Larsson, 2003), which is what buildings are. In summary, it can be contended that BIM as a process can benefit from the concept of shared situational awareness since its underlying intentions require dynamic virtual collaborative working. Regardless of the sophistication of BIM technology, the people-aspect is critical to a successful collaboration process. Understanding how people actually work in groups is therefore essential.

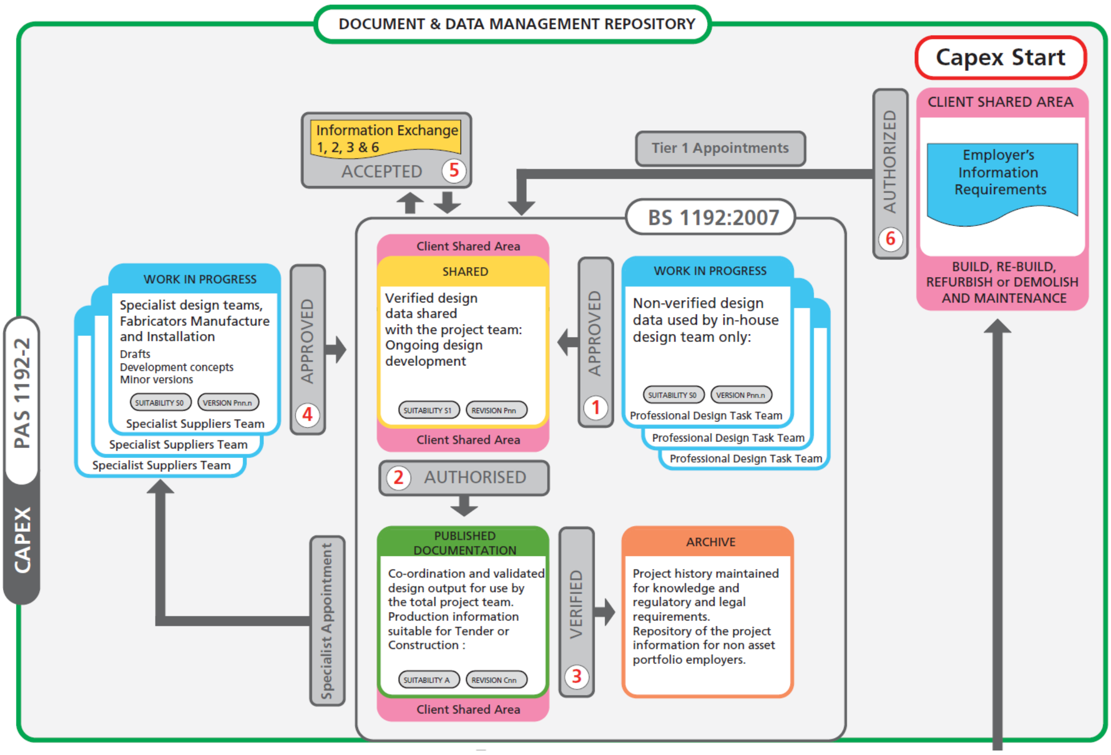

FIG 5: Structure of a CDE at the design phase (Source: BSI, 2013)

3. HOW PEOPLE WORK IN GROUPS: A THEORETICAL CONTEXT

In collaborative or group work, a taxonomy which defines two fundamental types of tasks and two types of outcomes had been proposed by Steiner (1972). Tasks can be *divisible* or *unitary*. Divisible tasks are specific pieces/items of work that can be assigned to specific individuals. For unitary tasks, subdivision of labour is not an option because for these tasks, joint or simultaneous team effort is a pre-requisite to desirable outcomes. For the outputs of collaborative working, two types of outcomes are also possible. An outcome can either be geared towards *maximisation* or focused on *optimisation*. A maximisation effort is when participants try to produce many results, e.g. when team members brainstorm over a list of potential roofing styles or composite wall system for the building envelope. Another maximisation analogy is when members of a group are all required to exert individual effort (no matter how small) in pulling a rope e.g. in a tug of war. An optimisation effort on the other hand, occurs when for example, the materials properties of a selected composite wall are 'collectively fine-tuned' towards achieving a desired level of thermal insulation (U-value). This would occur through an iterative process which stops only when a satisfactory envelope system design is achieved. In addition to group tasks and group outputs, the composition of groups, their mode of communication, 'group consciousness' and group size can also impact on the overall outcome.

Forsyth (2010) expanded on Steiner (1972) taxonomy of group tasks by considering individual focus and group focus. He defines a 'group mind' as collective consciousness which is a mental force that binds members of a group, i.e. fusing their discrete consciousness into a 'superior consciousness'. By having a multi-level view of groups and their outputs, it becomes evident that just as individuals make groups, groups themselves are constituent elements (Figure 6) of a wider context. This wider context can manifest as social divisions, organisations, communities, ethnicities and nations. Larsson (2003) has reasoned that because interaction and communication in the design process occurs amongst people who function in social settings that are often complex, the technical end product of design cannot be divorced from its social influences. Cultural diversities and social influences of collaborative design teams are hence useful and can supplement the technical design process (Sher et al. 2009). In other words, situated awareness, when ‘shared’ across social boundaries could enrich the creative outcome of collaborative efforts.

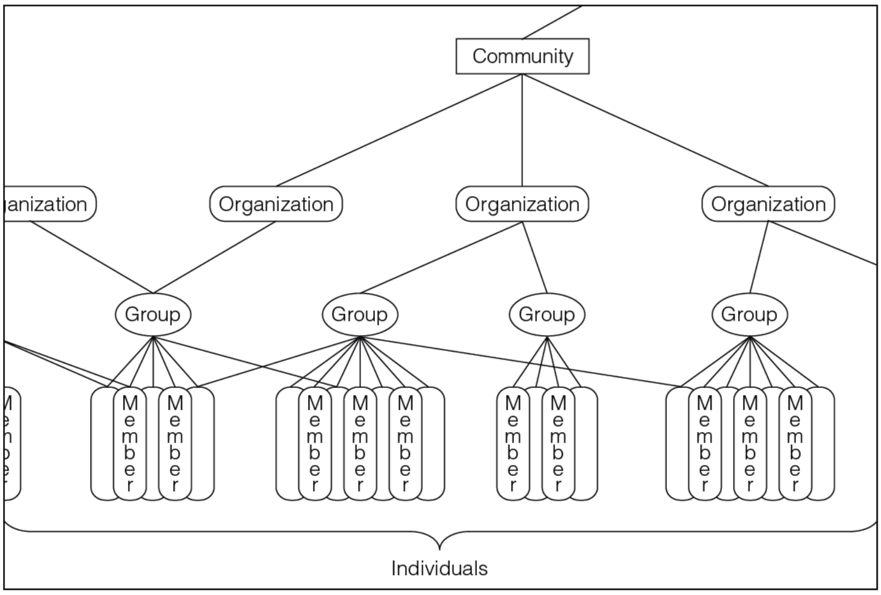

FIG 6: Multi-level view of groups (Forsyth, 2010)

The size of a group affects the quality of outcomes depending on the competencies of constituent members and the allocation of tasks (Steiner, 1970). In scenarios where the any member of the group is capable of delivering the desired outcome, the potential productivity of the group is linked to the resources (and resourcefulness) of its most competent member. In this case, the task is said to be *disjunctive,* and as the group size increases, so does the likelihood that at least one member is capable of delivering a satisfactory result. On the other hand, if the potential productivity of a group is dependent upon the resourcefulness of the least competent member (i.e. the weakest link); the task is said to be *conjunctive* and as group size increase, the probability of potential productivity decreases. An example of a conjunctive task is a scenario when three members of a group are asked to finish three types of BIM models (Architectural, Structural and MEP) by a specific date for clash detection and approval (or payment) by client to be assured. In this case, the potential productivity of the group depends on the date of completion of slowest or ‘weakest’ member. Such scenarios can be expected in Level 2 or Level 3 BIM where because models are to be aggregated, meeting deadlines or achieving desirable solutions will be complicated by cross-professional, social and interpersonal matters. This sophistication could be a key benefit of BIM collaboration but it is not obvious that sizes and compositions of professional BIM teams (groups) are currently determined based on disjunctive and conjunctive tasks. Obviously, it would be better if designers did not work in visual isolation. As argued earlier, with co-creation, the aggregation of models (and clash detection) may be unnecessary. However, resistance towards ‘controlled interference’ and co-creation may be expected if it is perceived, for example, as further erosion of architect’s control (Hamza and Greenwood, 2009) or dilution of their ‘professional identity’ (Alsaadani and De Souza, 2012). Nevertheless, social theory and behavioural science theory have been applied in understanding the decision-making processes of geographically dispersed design teams who used game-like virtual reality systems for collaboration (Goulding, et al. 2014). The size and complexities of globalised AEC teams, where cultural, temporal and organisational barriers manifest in group efforts, requires that their ‘interaction space’ must enable team culture, trust building, as well as team/meeting process (Pena-Mora, et al. 2009). As such, the requisite ‘social atmosphere’ must be created. This is where Social BIM can fill the gap by enabling shared situational awareness to be applied to the procedural aspects of BIM for the purpose of co-creation at Level 2 and Level 3 maturity.

4. REDEFINING SOCIAL BIM (SBIM): A FRAMEWORK

The social aspect of collaborative working is one which enables sense of community, democratic interaction, teamwork and leadership with ease of communication (Owen et al, 2006). In this regard, attempts have been made to embed socio-cultural inputs in technical design process. For example, social network virtual design studios SNVDS (Schnabel and Ham, 2012) was proposed to facilitate social intelligence, permit ubiquity via mobile computing and even help create new kinds of cross-cultural building forms due to socio-technical collaboration. Social bonding or social skills among collaborative design students in the study by Becerik-Gerber, et al. (2012) seemed as important as software skills, affecting the initiative of specific individuals to overcome technical difficulties and, crucially, ask for assistance. However, the absence of real-time shared situational awareness probably explains why some students struggled to keep pace with other students' models/progress (Becerik-Gerber, et al. 2012). This could be linked to their visual isolation during the collaboration process as well as lack of exchange of qualitative data about the design, in the form of audio-visual peer support and feedback. The perception-action cycle in social BIM occurs through a cognitive framework of how people actually work (Neisser, 1976) for workspace awareness, so that participants can exploit the mutual dependencies between their memories, their perceptions and their actions (Adams, et al. 1995). This would create a superior group consciousness (Forsyth, 2010).

Qualitative data used in BIM processes tends to be in the form of material descriptions as well as properties, taxonomies and families of parametric objects. There are also examples of use of qualitative building data for heritage documentation in the form of historic photographs, music and oral histories such as done by Fai, et al. (2011). There is however, a lack of evidence that qualitative data generated during the socio-technical modelling process itself has been captured and considered useful to collaborative BIM outcomes. Largely missing in existing collaborative design and cloud-based BIM processes therefore, is the capacity of peers to socialise and to simultaneously interact with (and edit a BIM) model. These peers would be supported by real-time visualisation of changes, without needing (or waiting for) synchronisation. Although classified by RIBA (2012) as a type of 'collaborative' or 'integrated' BIM, Social BIM ought to be considered as an interactive/multimedia and 'situation aware' mode of BIM where technical interaction with a BIM model and social interaction with team members, is near-absolute. The focus of this research, therefore, is to juxtapose the concepts of collaborative/integrated BIM and SNVDS in order to delineate Social BIM (SBIM) as a distinct process of collaborative design. In this regard, qualitative data generated by team members either proactively (just-in-time) or reactively (on-demand) can be helpful for technical support as well as in democratising decision-making and collaboration process. This research objective is met by developing a framework (Figure 7) which leverages on real-time shared situational awareness as well as optimisation/maximisation of unitary or divisible tasks amongst team members. This proposed framework was tested with practicing AEC professionals.

The advantages of the redefined SBIM are many but some important ones explored in this research include: (1) Participatory and concurrent manipulation of BIM models allows instant visual assistance and/or feedback to all participants (instant visualisation being key) to the *shared situational awareness*; (2) designers using shared workspaces e.g. those in the UK obliged to use common data environments (CDE) by BS1192-2007 (BSI, 2007), do not have to wait until BIM models are uploaded into the 'Shared' folder before they are able to participate or advise on the embryonic design; (3) the co-creation process mimics the way in which buildings are collectively constructed on sites, where team effort occurs with 'controlled interference' amongst the trades and disciplines; (4) participants are able to have embedded virtual multimedia communication interface where text, video and audio signals are sent and received in real-time within the same collaborative graphical user interface. This enriches the co-creation experience and generates qualitative data on the modelling process; (5) each participant, commensurate with their role can be given unrestricted or partial accessibility to the surrogate server (host PC); (6) there is a cost-saving when for example; only one computer system has BIM software installed in it, as opposed to central servers and all other local machines needing to run BIM software; (7) the SBIM concept would be a cost-effective option for SMEs wanting to adopt BIM process since relatively inexpensive available technologies can be adapted to achieve collaboration, with the benefit of shared situational awareness.

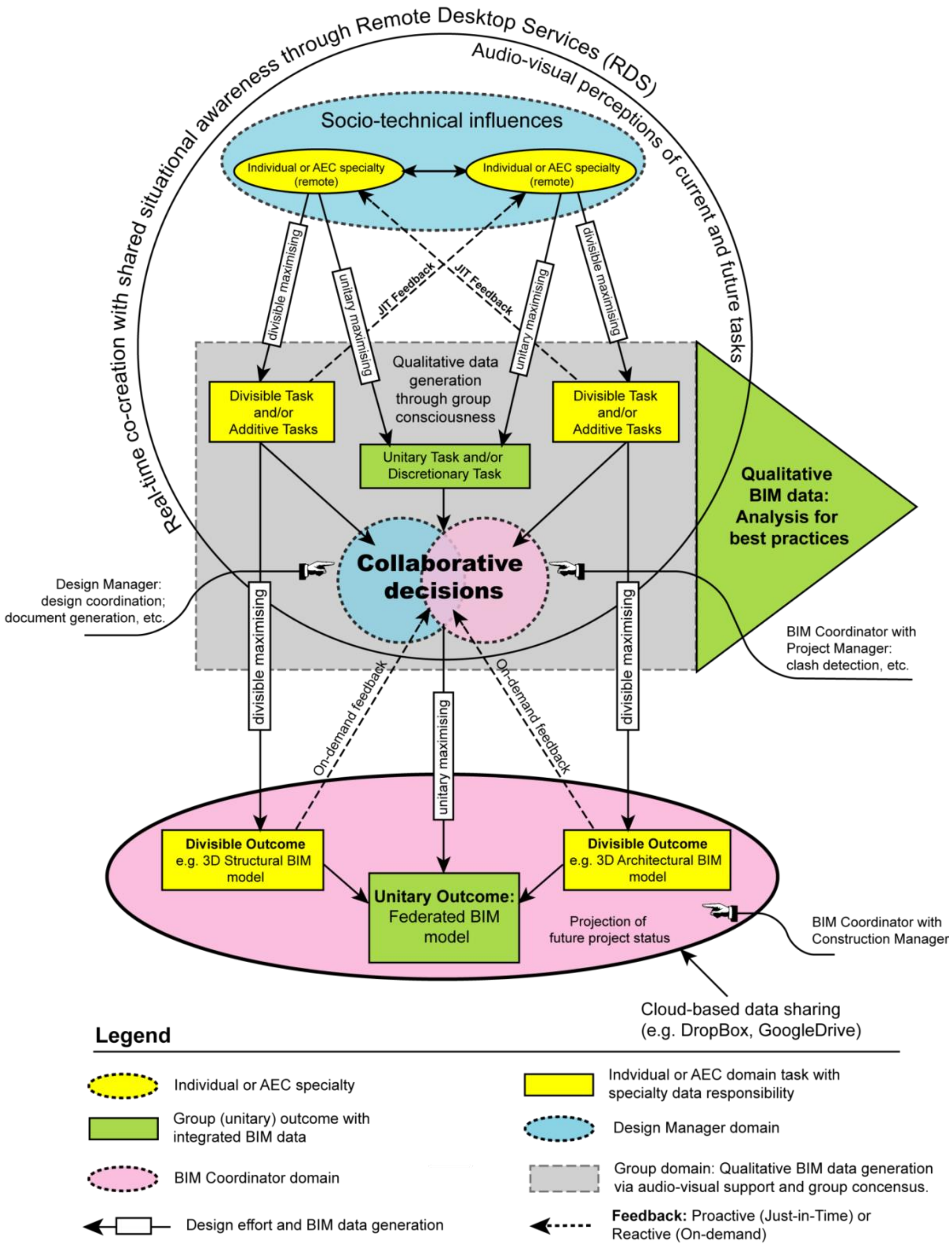

FIG 7: Proposed framework for Social BIM (SBIM) with shared situational awareness

5. RESEARCH OBJECTIVES

Building on contemporary literature and the identified gaps, the specific objective of this research is to provide proof-of-concept on Social BIM using three 'objectives' on collaboration with shared situational awareness. These objectives include investigating:

- the benefits of co-creation at the early design process, as opposed to the isolated and 'unverified' design residing the 'WIP' folder in CDEs;
- the willingness of designers to allow other specialists to intervene by providing timely and valuable input especially in the early design phase where key decisions are made - as well leveraging on the knowledge and skills of remote team members; and
- the cost-effectiveness and practicality of real-time remote desktop sharing services and cloud-based repositories as alternatives to dedicated common data environments, which can be exploited by SMEs for BIM processes.

6. MATERIALS AND METHODS

The exploratory investigation setup involves a quasi-experiment using an internet-based desktop sharing and communication system i.e. GoToMeeting (Citrix 2013a). Through this platform (Figure 8), 14 pre-selected globally dispersed volunteers accessed and controlled the GUI of Autodesk Revit hosted by a laptop computer in the UK. Participants were allowed to use individual cloud storage (Dropbox and Google Drive) but to grant specific folder access to others. The participants comprised of 10 architects, two (structural) engineers, a construction manager (with civil engineering background) as well as a project manager with an architecture background (Table 1). The 14 participants were drawn from four countries: United Kingdom (UK); United States of America (USA), Kingdom of Saudi Arabia (KSA) and United Arab Emirates (UAE). Only five participants identified themselves as native speakers of English, with six being of Asian background and three originating from mainland Europe. All of them were chosen based on their familiarity and experience with Autodesk Revit in particular and BIM concept in general – but none of them had previously used GoToMeeting (GTM). Among these 14 participants, three self-assessed levels of Revit/BIM expertise were identified: 2 beginners; 5 intermediate users; and 7 advanced users. All users were pre-selected on the basis of having access to fast broadband connection, determined as ≥ 70Mbps for download and ≥ 30 Mbps for uploads.

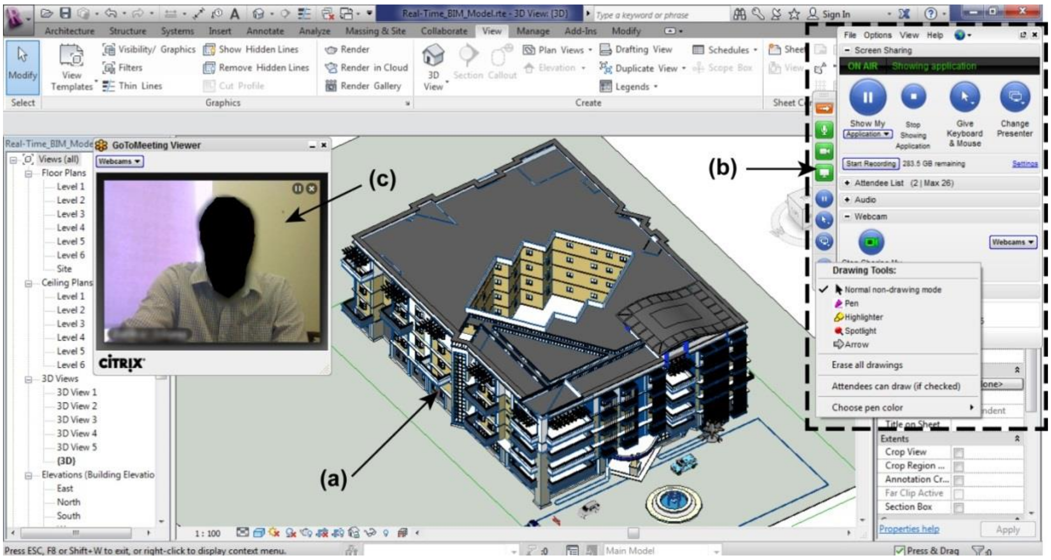

FIG 8: Revit GUI with (a) remote controlled BIM model (b) GoToMeeting menu and (c) floating video screen

Four participants were equipped with desktop PCs while nine participants used laptops. Participants were encouraged to also participate in a secondary role using handheld devices but one participant used a Tablet PC throughout. Multi-tasking by participants was strongly discouraged as this may impact on system performance and bandwidth availability if the internet is used concurrently. All users were asked to use their default Dropbox and Google Drive free accounts for storing files. A semi-structured interview cum observation of user experience was conducted during several collaborative design sessions with participants. At the end of each session, participants were also required to complete a questionnaire which aimed to capture their experience.

The design tasks involved partially complete architectural and structural BIM models. Users were expected to edit/modify these models, first as individuals and as team members working collaboratively. In some instances, both the architectural and structural BIM files were co-located in the host user's laptop PC. Subsequently, versions of the model were stored in Dropbox and Google Drives of specific members, from where team members were able to access the files. The use of tools like 'Link Revit' allowed de-coupled architectural and structural models of the building to be merged using a third model that was also saved in Dropbox/Google Drive. In this regard, four collaborative BIM network protocols were conceived: One-to-One; One-to-Many; Many-to-One; and Many-to-Many (Figure 9), but only three were adopted for this study.

6.1 One-to-One Protocol

In this protocol, the host user's PC is acting as a surrogate server, allowed only one remote user to interact with Revit model. This interaction was only possible after necessary accessibility levels were granted (Figure 9a).

Cloud storage was not shared in this scenario since only one participant could save/access the BIM data. Eight participants took part in the sessions that employed this protocol. In this instance only a single GTM licence is required.

6.2 One-to-Many Protocol

This protocol allowed the host user's PC to have a one-way interaction with other designers/participants, who were not allowed to take control of the surrogate server, but could participate in the design development process, primarily by real-time audio-visual feedback (Figure 9b). The One-to-Many was not actively pursued in the experiment due to time and resource constraints.

6.3 Many-to-One Protocol

This protocol enabled remote participants to take turns in co-creating the 3D architectural and structural BIM models, even in the occasional absence of host user (Figure 9c). It was necessary to disable screen savers or desktop/laptop hibernation modes. Seven participants were involved in trying out this collaboration protocol. In particular, tablet users only took part in these types of sessions.

6.4 Many-to-Many Protocol

In this scenario, all desktop/laptops were allowed to swap roles of surrogate server. Participants took turns to act as 'organisers' by inviting and granting access to their systems (Figure 9d). This protocol depends on the 'nomadic server'. Specialty BIM models were saved in shared Google Drive, from where each host would take turns to upload (link) and integrate the final 3D model. The 'Link Revit' tool allowed smaller/specialised Revit files (e.g. structural frame system) to be saved in separate cloud locations from where they could be uploaded into a central coordinated Revit model. Only four participants participated in testing this protocol.

The Many-to-One and Many-to-Many participants were presented with a Multi-floor residential BIM model which was comprised of both Revit Architecture and Revit Structures sub-models. For the One-to-One participants, a combination and/or choice of one storey and multi-floor BIM models were utilised.

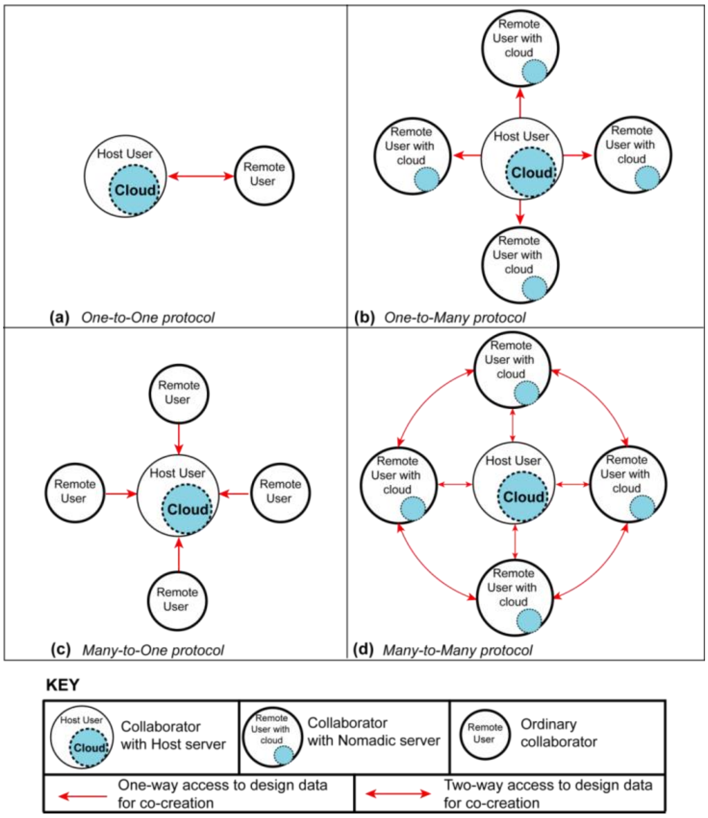

FIG 9: Collaborative real-time BIM network protocols used with Revit Architecture through Remote Desktop Service (GoToMeeting).

In each collaborative network protocol, an initiator or ‘organiser’ had to invite other users to the meeting session. The organiser’s system (laptop/desktop) then acted as a surrogate server with files occasionally saved into the hard drive and/or a ‘cloud server’ which in this case was typically a Google Drive. Some multi-user session participants were able to save their Revit files in Dropbox and these Revit files were then shared or accessed by other users during the collaborative sessions. Each participant was warned to ensure that upon inviting others/granting access to their computers, the level of accessibility should be restricted to Revit application only and not the entire ‘screen’ as this could allow unlimited access to their computers (including email; hard drive and web browsing history). Managing the Many-to-Many process was done based on the collective understanding that all identified collaborators should be granted access if/when they request it. The design tasks to be carried out were generally outlined and scheduled according to professional specialisations of participants. The participants were required to spend at least 30 minutes per session but three members spent over one hour (Table 1). These participants clearly spent more time engaging themselves through the remote desktop service.

TABLE 1: Profiles of participants in the real-time collaborative modelling exercise

ID	Profession	Role during experiment	Location	Years of Revit Experience	Revit expertise (self-assessed)	Duration of exercise (hr:mm)	Type of device (Revit Installed?)	Collaborative network protocol
A	Architect	Architectural design	UK	10	Intermediate	1:04; 0:37	Desktop PC (Yes); Tablet	Many-to-One
B	Architect	Architectural design	UK	3	Beginner	0:37	Laptop	One-to-One
C	Engineer	Structural design	UK	5	Intermediate	1:50; 0:28	Laptop; (Yes)	Many-to-Many; One-to-One
D	Architect	Architectural design	UAE	7	Advanced	1:05	Laptop	One-to-One
E	Architect	Coordination of models	UK	5	Intermediate	0:55; 0:34	Desktop PC; (Yes)	Many-to-Many; Many-to-One
F	Architect	Architectural design	USA	8	Advanced	1:23;	Laptop (Yes)	Many-to-Many
G	Architect	Architectural design	USA	4	Advanced	0:55; 0:32	Desktop PC (Yes); Smartphone	Many-to-One; One-to-One
H	Construction Mgr.	Coordination of design	UK	4	Intermediate	0:32	Tablet	Many-to-One
I	Architect	Architectural design	KSA	4	Advanced	0:54; 0:25	Laptop	Many-to-One; One-to-One
J	Engineer	Structural design	UK	6	Advanced	1:56; 0:40	Laptop (Yes)	Many-to-Many; Many-to-One
K	Architect	Architectural design	KSA	7	Advanced	0:42	Laptop	One-to-One
L	Project Manager	Coordination of design	UK	2	Beginner	0:36	Laptop	One-to-one
M	Architect	Design manager	UK	5	Intermediate	0:58; 0:32	Laptop (Yes); Smartphone	Many-to-One
N	Architect	Coordination of models	UAE	8	Advanced	0:35	Desktop (Yes)	One-to-One

7. DATA COLLECTION, ANALYSIS AND VALIDATION OF FRAMEWORK

The collaborative network protocols (Figure 9) were tested at both individual and multi-user levels, which began with organiser/author granting participants' access to Revit via a shared screen (Figure 8) with keyboard and mouse control. Out of the 14 remotely located participants, only eight of them had Revit installed on their own computing devices. There were four desktop and nine laptops involved (Table 1). In the Many-to-Many sessions, participants who had Revit installed in their computing systems (laptops/desktops) took turns to grant equal access to other participants. Participants of multi-user exercises had the option of partaking in further sessions using either a Tablet PC or a Smartphone. Participant A subsequently connected with a Tablet, while Participants G and M accessed the network via Smartphones. Participant H was the only individual to connect with a Tablet throughout. The sessions were generally structured around navigating a given BIM (architecture) model although in some multi-user sessions, some participants presented their own models for manipulation by others.

7.1 Desktop PCs and Laptops

The protocol sessions had different durations since participants were often taking part in exploring more than one kind of protocol (Table 1). Some of those who participated in Many-to-One sessions also partook in dedicated One-to-One sessions, hence Participants C, F, A, G judged the Multi-participant session to be more exciting, while E and M considered it more stimulating as an information exchange process. Participants C, E and J, were particularly excited by being able to share/manipulate Revit with many users at the same time although the perceived delay in mouse action and model response was regarded as 'mildly noticeable by Participants J, H and M. Whenever a presenter (who was not an organiser) needed to have more control over other participants, it was necessary for the current 'organiser' to relinquish their status to someone else. This required login out and allowing the new organiser to login again and re-inviting all participants. This was a slight drawback as it would have been preferable (Participants E and M) if the role of organiser can be switched within a session, just as presenters can be switched. Without earphones, there was often a tendency for echoes to be heard over the default on-board speakers of these devices.

7.2 Tablets and smartphone

The performance of Tablet PCs was evaluated separately by two separate UK-based individuals in remote locations: one in London (Participant A) and one Leicester (Participant H). The tablets tested included one iPad2 device and one Samsung Galaxy device. Each device download the GoToMeeting App designed for their devices. The Smartphone participants were based in the UK (Participant G with iPhone 4) and USA (Participant M with Samsung S3). Manipulation of the 3D model on the host PC was however impossible by these handheld devices. This limitation was verified by (Citrix, 2013b) as a constraint due to the unique operating systems of Tablets and Smartphones. Their touchscreens only allowed visualisation of Revit models being manipulated by other remote participants. The video window and chat facility could be brought up with both types of devices. There was no reason or evidence that there were differences in the performance of these handheld devices which operated under two unique operating systems: iOS (iPad/iPhone) and Android (Samsung Galaxy/S3). All users of these devices complained however of echoes, delays and occasional cessation of sounds in the transmitted audio. The quality of audio was found to improve using a headphone, with negligible echoes. Mobile device users could not visualise the annotations made with drawing tools by the laptop/desktop users were not visible on the smartphone.

7.3 Model exploration and manipulation: keyboard and mouse control

For desktop and laptop users, the organiser of each session had a default priority for keyboard and mouse control. Selected participants could be granted remote control of the Revit GUI, but the organiser would override this access each time the mouse/keyboard of host PC was in use or slightly touched/moved. All laptop/desktop users were able to edit materials, delete objects and create new parametric 3D objects, but all saved files were in the host computer. In a mini problem-driven session when participants were asked to edit a roofing system of the multi-floor residential BIM model, Revit files were saved directly to cloud (Google Drive), from where members could download local versions and Participants E (UK, intermediate Revit user), Participant F (USA, Advanced Revit user), and Participant M (UAE, intermediate Revit user), were able to compare their individual model changes before deciding to adopt the version edited by Participant M. Although they reasoned that the model by Participant F was the most developed, conceptually, they preferred the design by Participant M because it was aesthetically more 'pleasing', as they collectively judge it visually. Participant H using a Tablet PC was only able to give audio-visual feedback was helpful in the roof selection process.

Users acknowledged that it was during the execution of more complex tasks - e.g. the creation of new objects such as a wall (Participants C, F and J); adding a new component such as doors/window (Participants E and F); or the changing of parameters of an object through dialog boxes (all multi-user participants) that the relative system sluggishness due to bandwidth limitations were perceived. The Many-to-One participants did not appear to perceive such sluggishness, except after some of them (Participants E and J) compared their experience with Many-to-Many sessions. Participants B, F, I and M who used laptops, found that using a mouse was indeed better than touchpads in delivering a better model navigating experience although Participants B and M felt that architects would likely use a mouse for any serious interactivity with 3D models.

During model exploration and navigation, switching off (i.e. hiding) redundant design features (landscape, internal stairs), reducing the level of detail (LOD) of the BIM model and using basic non-rendered surface materials was particularly helpful in speeding system performance. Participants A, G and M who used handheld devices perceived that this strategy reduced the 'stress' on real-time graphic processing on their mobile computing systems, allowing the visualisation experience to be smoother and faster. Participants A and G who had previously connected with Desktop PCs also felt that this capability made navigating the remote BIM model with the scroll mouse much faster and less 'jerky'.

7.4 Productivity with Just-in-time (JIT) and on-demand (OD) feedback

Participants in all three collaboration protocols expressed satisfaction with the experience of real-time remote control of a computer, especially the unlimited ability to edit the BIM models (desktop/laptop users). Two kinds of feedback emerged: just-in-time (JIT) and on-demand (OD) feedback. JIT feedback was found to be helpful in the early design stage, and it was given proactively. The reactive OD feedback was mostly applicable when opinions of design outcome were sought from others. In the post-trial survey, 8 out of 14 participants 'strongly agreed' that this process could aid collaborative work, four 'agreed' while only two 'disagreed' with this notion.

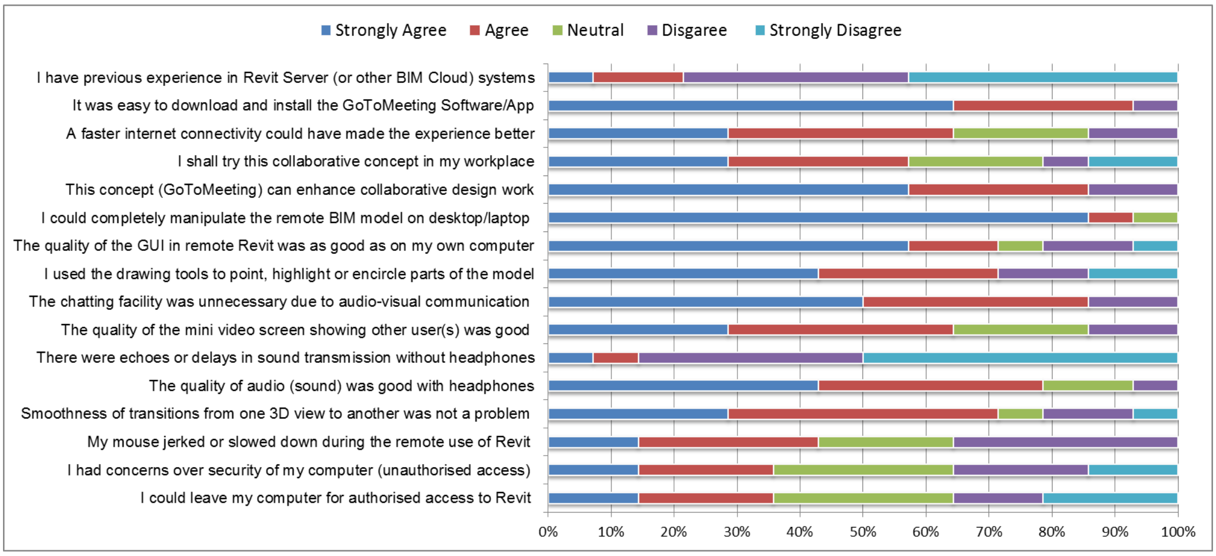

FIG 10: Post exercise survey response of participants on their experience of remote participatory control of Revit via GoToMeeting

The embedded chatting facility was found to be largely dormant (i.e. 7 'strongly agreed' and 5 'agreed') and unnecessary due to audio-visual communication. However, in the One-to-One session, Revit beginners (Participant B and L) benefitted from receiving relevant tips and links to Revit tutorial via the chat facility, and they were (not surprisingly) the same respondents who 'disagreed' (Figure 10) that the chat facility in GoToMeeting was unnecessary. Both respondents used OD feedback substantially due to their low-level of skill and experience with Revit. Multi-participant engagement was enhanced in GoToMeeting using the drawing tools including Pen tool, Highlighter tool, Spotlight tool and Arrow tool. These were used to informally annotate the models, generating another form of qualitative (illustrative) data. The organiser has to grant tool privileges to participants.

A summary of the strengths and weaknesses of the various protocols has been provided (Table 2) in terms of accessibility to remote systems and abilities of participants to carry out divisible or unitary tasks. Although the concept of shared situational awareness was not mentioned to the participants prior or after the experiment, all participants of the Many-to-One session (i.e. C, E, F and J) liked the idea of being able to instantly view progress of other participants and giving timely OD feedback. An example of OD feedback and real-time support occurred between two engineers with different BIM skill levels: Participant C (a UK-based intermediate Revit user) received guidance about Revit Structures from Participant J (a UK-based advanced Revit user) and on few occasions, Participant J took total control of the most difficult structural modelling tasks. This occurred through the remote control of Revit installed in the UK-based laptop from the US-based desktop.

TABLE 2: Summary of strengths and weaknesses of the protocols

		One-to-One	**One-to-Many**	**Many-to-One**	**Many-o-Many**
Accessibility	Uni-directional access and control of remote PCs only		x	x	
	Multi-directional access and control of remote PCs possible	x			x
	Direct access to central cloud storage		x		x
	Restricted number of concurrent users (single GTM licence)	x	x	x	
	Unrestricted number of concurrent (Multiple GTM licences)				x
	Mobile device participation	x	x	x	x
Design process	Annotation of models and documents	x	x	x	x
	Audio-visual feedback	x	x	x	x
	Divisible optimisation of same building modelling tasks	x	x	x	x
	Unitary optimisation of same building modelling tasks	x		x	x
	Divisible maximisation of same building modelling tasks	x	x	x	x
	Unitary maximisation of same building modelling tasks	x		x	x
	Optimisation of multiple building modelling tasks	x			x
	Maximisation of multiple building modelling tasks	x	x		x

Audio-visual recording of GoToMeeting sessions was possible but only done for the One-to-One and Many-to-Many protocols. Users had a choice of saving the media files in the native GoToMeeting file or in Windows Media Player format. The multiple use of video facility is restricted to six webcams per session (Citrix, 2013a), and internet bandwidth determines the audio-visual experience (Citrix, 2013b). Hence only participants who were speaking extensively or who were 'organisers' were asked to transmit/activate their webcams. Other participants could receive the video signals of the speaker/organiser in a small window on their screen while they remain 'unseen' until such a time when they were required to speak or actively demonstrate a concept on their own computers. The qualitative data collected served as minutes of meetings and was also analysed by individuals for personal reflection and in one instance, to settle a minor disagreement.

The chat facility of GoToMeeting was used collectively in the multi-user sessions to send hyperlinks to online documents or specific instructions to individuals mostly at the beginning when technical difficulties with joining the meeting or audio quality were encountered. Occasionally, chatting was used by participants to send discreet messages to authors/organisers by specific individuals especially in the One-to-One and Many-to-Many sessions. For example, it was also possible to share links to Revit videos on YouTube with Participants B and L (beginners) who wanted elaboration on some aspects of BIM modelling during the One-to-Many session. Although this communication was done via chatting, on at least one occasion, a YouTube video was watched by all participants in the Many-to-Many session. The telephone call feature of GoToMeeting was not used by any of the participants in any session.

8. DISCUSSION

In group work, the execution of tasks could be achieved by maximising or optimising outcomes and the tasks could be unitary or divisible. As argued by Gutwin and Greenberg (1999), in a truly collaborative situation, participants must *be involved in another task*, (i.e. that of collaboration), hence their workspace (situation) awareness has to involve both their own domain and the collaboration needs of others. This study has shown that using native BIM files, the design outcomes achieved are linked to their skill sets, available technology, the ambient socio-cultural influences as well as shared situational awareness. The coherence and continuity offered by remote co-creation delivers a new experience to collaborative (Revit) modelling using GoToMeeting as a groupware. This remote desktop sharing tool allowed professional interdependencies and brought a 'sense of community' (Owen, et al. 2006) to the participants in this study. With real-time shared situational awareness, difficult aspects of Revit modelling were delegated to the most experienced members of the 'closed group' regardless of their core professional background, as this research has shown. In situations where work was apportioned to individuals (divisible tasks), sometimes success was dependent upon members taking sequential turns to produce an outcome that was the sum of individual efforts. This was a clear example of *divisible tasks* manifesting in the form of *additive tasks* (Steiner, 1972). The architect (Participant F) editing the Revit model, which was then used by structural engineer (Participant C), is an illustration of a scenario that could play out in real-life building design process. However, unless a professional (e.g. an architect) is willing to allow 'permissible interference' with his work; the fear of losing control (Hamza and Greenwood, 2009) or diluting their professional identity (Alsaadani and De Souza, 2012) will remain a bottle neck. How a new generation of architects and engineers are trained will be important in changing mind-sets, but the shared workspaces will also need to permit co-creation.

Nevertheless, the output of a preceding additive task can determine subsequent additive tasks - as well as the final outcome. In the execution of unitary tasks, weights of tasks may also be assigned disproportionately (with members' consensus), commensurate with the perceived/factual differences in the levels of individual skill. This is a case of a *unitary task* transforming into *discretionary tasks* (Steiner, 1972). Through this approach, members of a group (Many-to-Many) working on a BIM model, agreed to leave the most complex part to the most experienced Revit user in the group. For example, Participant C, a UK-based intermediate Revit user left some difficult aspects of Revit structures modelling to Participant J, a UK-based advanced Revit user. This is a demonstration of discretionary tasking made possible by the social atmosphere created by GoToMeeting which enabled the BIM collaboration. The generation and sharing of qualitative data and during the process was also unique.

In terms of hardware, handheld devices (tablets/smartphone) are severely limited for interacting with the host system or co-creating. Although this is an issue for groupware developers to consider, such devices are hardly suitable for serious modelling work but perhaps this is because 3D modelling software are presently designed for keyboard and mouse (not fingers and pinching). In this study, the performances of handheld devices were found to be acceptable if passive (non-interactive) participation is desired. Participant H was a construction manager who had little need to make active creative input into the BIM modelling process, but his JIT feedback was helpful in the selection of a roofing system. Handheld devices could be beneficial in instances where, for example, users are commuting or are in a situation where their full manipulation of 3D BIM software is either unnecessary or not permissible (e.g. a client). In the near future, it is expected that wider access to 4G technology will ease connectivity and further enrich the experience of users, especially during multi-tasking.

Because the GoToMeeting system uses internet connectivity, as opposed to granting firewall access to a server to remote users, the risks posed to other members of an organisation are minimised. The use of freely available cloud-based storage systems like Google Drive as well as the ability to have a single installation of BIM software (which can be shared and controlled by others) could have cost-savings in building projects. For Dropbox, up to 10GB can be transferred at any single transaction. There was no issue with handling large files for this case study, whose final size of model (and supporting PDF documents) was 800MB. For more complicated models or larger projects, it is likely that more storage will be required. It is possible to upgrade paid versions Dropbox Pro (1TB), Dropbox Business (Unlimited) and Google Drive (up to 30TB). The flexibility of accessing remote computers (surrogate servers) linked to cloud storage also adds to the feasibility of the proposed framework. This is in addition to the flexibility and mobility of servers, since any laptop/desktop running Autodesk Revit could act as a server in the three protocols explored.

Organisers and presenters need to carefully consider in advance, what they want peers to view on their entire screen. There is potentially unlimited access to all installed applications including minimised software/webpages or hard drive. It is nevertheless often helpful for all participants to view non-design applications such as text-based documents (e.g. design brief) and spread sheets. Without these considerations and controls properly initiated, security and privacy of users may be breached. For example, participants in this study were reluctant to leave their computers unsupervised under the Many-to-One and Many-to-Many protocols even if they had restricted access to Revit only. This cautionary response to a 'new' collaborative working process requires new security-conscious habits as well as confidence in the security features of the remote desktop sharing system.

9. CONCLUSION

This research developed and validated a procedural framework for Social BIM (SBIM), by demonstrating real-time shared situation awareness amongst selected group of remotely located users. Four collaborative BIM network protocols were conceived out of which three were tested using a commercial communicating and teleconferencing system (GoToMeeting). Design tasks were divided according to skill levels and professional expertise either as divisible tasks or unitary tasks. Some divisible tasks were found to be additive tasks and were carried out with real-time visual consensus/feedback such that outcome of preceding tasks were optimised and primed for subsequent tasks. Some unitary tasks ended up being discretionary tasks, taken up voluntarily by highly experience members of the group, with others participating with real-time audio-visual feedback. In this study, discretionary tasking worked very well towards optimising of group resources (i.e. the most skilled Revit user and the most creative designers produced the most desirable results). When the overall task was geared towards maximising, the goal is to achieve as much outcomes with as many inputs (i.e. generating roof design alternatives). Participants largely expressed willingness to exploit this concept in their workplaces but a best practice manual may be necessary in order to optimise the concept (bandwidth optimisation, security, task delegation and time management).

The findings suggest that the desktop sharing software with appropriate technology and internet connectivity offer a feasible and even cost-effective alternative to team working using traditional BIM servers. The current structure of CDEs might not allow participants to be involved in other tasks, especially at the WIP phase. The fact that CDEs expect to host IFC files (which lose their parametric/editable characteristics) might not help designers who download them for local use. Also, multi-disciplinary additive task (i.e. whole building modelling) are currently being treated as divisible tasks which are for 'in-house design team only' in the WIP containers. This research suggests co-creation is helpful for optimum collaboration. Regardless of the nature of tasks (divisible or unitary), real-time visual consensus and consent are helpful to the sort of model aggregation desired for Level 2 and the integration expected for Level 3 BIM. The results not only help expand the horizon of contemporary options for collaborative working in BIM processes, but also allow remote teams to experience *shared* situational awareness. Social BIM (as redefined in this study) can focus on the *procedural aspects of BIM* by encapsulating the metacognitive, behavioural, interpersonal and confidence skills that shape effectiveness of collaboration. Just-in-time feedback, trust-building in executing divisible and additive tasks, voluntary or discretionary tasking, bonding via interactive (shared) workspace, inclusivity of cultural diversity as well as 'audio-visual' consensus in the modelling process are themes that have been explored in this study. The fusion of discrete consciousness into a superior consciousness amongst co-designers is helped by the 'democratisation' of professional feedback, which is made possible by real-time visualisation of task execution.

9.1 Limitations

The research has some limitations. First, co-creation as described here requires the use of same native BIM authoring software and it will be difficult to replicate same results with IFC models which are 'static'. Secondly, other socio-technical influences such as professional experiences, perceptions, biases and cultural factors were not investigated at individual levels. Further exploration and validation of the findings is required for more complex design tasks as well as enhancement of system security for industry application. The findings were also obtained from one building type with limited number of (non-random) participants with relatively short sessions of collaborative design activity. The study also used only one type of desktop sharing software (GoToMeeting) and one type of 3D BIM software (Revit) and did not consider MEP models. In addition, given that there is a relationship between group size and the competencies of members in productively carrying out disjunctive or conjunctive tasks (Steiner, 1970), then the limits to number of participants in GoToMeeting (currently 25) is a potential drawback for industry application. Finally, the legal and contractual requirements of server-based design collaboration systems (Singh, et al. 2011) not considered in this study/framework would usually be adopted in corporate settings. Nevertheless, this exploratory study represents an initial attempt to uncover the possibilities of more effective and efficient collaborative working required for Level 3 BIM processes.

9.2 Concurrent and future work

The Many-to-Many protocol was recently deployed by groups of students from three institutions across two continents: Loughborough University and Coventry University in the UK as well as Ryerson University in Canada. Two students from each institution formed a group with six members collaborating on a harmonised design brief. Preliminary findings have been summarised in Childs, et al. (2014) and Poh, et al. (2014).

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