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Stakeholders' Perceptions of Digital Collaboration in Delivering a Mixed-Use Housing Development Project: A Case Study in Australia

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Abstract: The paper presents an analysis of collaborative processes in delivering mixed-use housing developments, with a focus on the adoption and roles of digital collaboration to address complex challenges. Extending the collaborative practice (CP) model, the research utilises a qualitative approach and an instrumental case study involving nine semi-structured interviews with key stakeholders from an award-winning mixed-use housing development in Australia. The study identifies key collaboration elements, such as early project establishment, a well-defined brief, and an adaptive integrated digital plan relevant to the interdisciplinary team. The scarcity of successful "extreme" mixed-use cases globally highlights the need for a core conceptual model for collaboration in complex housing developments, focused on digital collaboration, to support future projects in the sector. The research emphasises social innovation in mixed-use housing developments and highlights the importance of effective digital collaboration for addressing environmental, economic, and social sustainability needs. Contributions to the field extend both theoretical and empirical aspects of the CP model, critically exploring the potential of digital collaboration in mixed-use housing projects. The findings reveal critical elements for establishing a digital collaboration plan, leveraging technology to enhance stakeholder experiences and project delivery. The research is especially relevant in the post-COVID era, where digital collaboration gains significance for the industry.

Keywords: digital collaboration; Building Information Modelling (BIM); mixed-use housing; construction management

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1. Introduction

Today, more than half of the world's population lives in urban areas, and the figure has been projected to increase, reaching 70% by 2050 (UN). As a result of rapid urbanisation, cities will face significant challenges in providing adequate infrastructure to meet the needs of the fast-growing population and urban developments [1]. The housing sector is critical for ensuring the success of an urban growth plan by accommodating the population in a way that improves their health, well-being, and quality of life [2]. However, the sector is facing numerous challenges in responding to the rising social, environmental, and economic demands across many countries, including Australia. The more significant issues include poor affordability, inefficient planning and construction [3], and poor housing quality, which has also been linked to serious health issues [4]. These concerns have been exacerbated by the global pandemic crisis, which brought an unprecedented negative shock to new demands for Australian housing (NHS). Such challenges will most affect the economically and socially vulnerable groups, exposing them to a shortage of affordable and reasonable quality housing with access to inclusive infrastructures and social services [2].

For over a decade, mixed-use development—with a diverse mix of residential, retail, commercial, social, and entertainment spaces all in one structure—has been recognised as an optimal solution to numerous urban challenges, including social, economic, and environmental ones [5]. Such multifaceted programs can promote social equity and inclusiveness by offering a variety of housing options to people with a wide range of economic abilities. These potential social benefits of bringing a diverse range of amenities and services together can lead to enhanced safety and increased movement independence, especially for socially disadvantaged groups [6].

However, successful mixed-use housing developments, especially extreme mixed-use cases, are very scarce in many parts of the world, including Australia. This solution is complex and has challenges in its implementation. Despite their potential benefits, the housing sector has been very slow in developing such mixed-use buildings mainly due to the multifaceted complexity encountered in their planning, design, and construction stages compared to single-use buildings [5]. The development and construction of such structures often involve stakeholders from multiple disciplines and organisations, including multiple contractors and project teams, as well as various financial sources demanding extensive collaboration to address this increased level of complexity [6]. Research has suggested augmenting the resources and capabilities of inter-organisational networks is key to responding to increasingly complex and turbulent environments [7,8], requiring an integrated workflow with information coordinated across different project stages [9,10]. In this context, innovative technologies for supporting effective digital collaboration become a potential solution to addressing (i) the fragmentation in the Australian housing construction sector [11], particularly in relation to socially responsive developments and (ii) the complex challenges in the development and construction of mixed-use structures. However, in the current literature and practice, the capability of digital technologies to support collaborative processes in the housing sector has not been adequately explored and fully understood.

This study aims to instigate an in-depth analysis of digital collaboration in mixed-use housing development and construction. By adopting the collaborative practice (CP) model developed by London and Pablo [11], this paper defines and investigates the key notions of the collaborative processes in delivering a complex mixed-use residential building and explores the effect and potential of digital technologies in supporting such processes. To achieve the aim, the research conducts a qualitative case study grounded in the interpretivism paradigm [12]. The case study utilises U City Case, (https://www.ucity.com.au/, accessed on 20 August 2023) an award-winning (for social impact) mixed-use housing complex in Adelaide, which represents one of the rare yet successful practices that incorporate a wide range of housing typologies, providing housing solutions to the older population, and people with movement difficulties, alongside retail and commercial spaces and social services in an urban context. Nine semi-structured interviews have been conducted with key stakeholders who were closely involved and undertook critical decision making in the development and construction of U city to understand the collaboration undertaken during the project delivery, as well as their perception of the roles of digital technologies in supporting collaboration for delivering such projects. The interviews provided a rich and unique dataset for us to carry out the in-depth analysis of the subject through transcription, open coding, axial coding, and selective coding.

2. Background

2.1. Mixed-Use Housing Developments and Social Challenges in Australia

In recent years, cities globally have focused on reducing their environmental impact while also seeking to catalyse social sustainability [13]. Many cities, particularly in Australia and the United States, have instigated policies to consolidate urban footprints through the development of medium- and high-density housing in inner urban areas to achieve this goal [14–16]. Some literature argues that social aspects have been largely ignored in the way housing policy is developed [17,18], while others highlight that governments have tried unsuccessfully to integrate social sustainability into housing policy [19,20]. One of

the key vehicles governments have utilised to address social sustainability in housing is pursuing an affordability agenda based on the development of periurban areas [15]. There is, however, growing recognition in the literature of the significant strain this development places on infrastructure [15,21] and its impact on health and well-being [22–26].

One of these social challenges is ageing. The global population is ageing at an unprecedented rate, with current estimates suggesting 21.1% of the global population will be aged 60 years or over by 2050 [27]. In Australia, this figure is estimated to be 22% by 2057 and reach 25% by 2097 [28]. This rapid growth brings significant challenges to the provision of appropriate housing and urban environments for the older demographic. Higher-density housing has shown a positive impact on the health and well-being of older people, but questions remain as to whether apartment living is adequately satisfying their physical needs [29]. Although traditionally overlooked in housing policy development [30], housing people with disabilities such as movement difficulties has become another challenge to be addressed in Australia since the introduction of the National Disability Insurance Scheme (NDIS) in 2013. Accommodation options for people with disabilities have typically been limited to family support, institutionalisation, social housing, or supplies from the private rental market [30–33]. The NDIS, however, provides people with disabilities significant financial resources to pursue new housing opportunities [34,35]. Under the above context, a number of new approaches have emerged for the development of housing, from the broader guidelines as to how cities should be developed [36–38] to specific housing models through collaborative planning and community development, such as those seen in cohousing [39,40] and to industry-focused guidelines such as those of designing for people with physical disabilities [41,42].

Mixed-use developments are primarily known as a response to the detrimental impact of urban sprawling, such as car dependency, traffic congestion, and air pollution [6], while also contributing to financial viability by diversifying the assets within one specific unit or area [43]. Mixed-use housing developments, by combining residential and a diverse range of nonresidential spaces under one (often vertical) structure, can perform a critical role in mitigating social challenges across multiple scales [44,45]. Such agglomerations, particularly in high-rise developments, are associated with positive impacts such as providing social cohesion [46], a sense of community [47,48], social support [46,49], social interaction [50,51], and social well-being and mental health [52]. These potentials are created by bringing the range of amenities and services together, which are especially beneficial to vulnerable or disadvantaged groups such as older people and people with physical disabilities, leading to enhanced safety and increased movement independence [6]. Although mixed-use housing developments have gained growing interest in the literature, practical examples in the sector are very scarce. An example of such a structure is Kampung Admiralty (https://architectureau.com/articles/kampung-admiralty, accessed on 12 April 2023) in Singapore, which offers a community hub in the form of an integrated building function designed to meet the needs of a variety of social groups, especially older people. The amenities and different functions embedded in the building allow them to be socially and physically independent and provide opportunities for leisure, fitness, and other voluntary activities. Another similar initiative in terms of design and functions is Inspir Carnegie Hill (https://handelarchitects.com/project/inspir-manhattan, accessed on 12 April 2023), a high-rise building in the US for housing and supporting older people and people with movement difficulties.

In this paper, social challenges for housing developments in Australia have been used as a basis to identify a suitable case study for the research investigation. U city, being the only vertical mixed-use housing development of its kind and scale in the country, provides us with unique access to a multifaceted network of stakeholders and organisations involved during its development and construction. Compared to conventional single-use projects, the collaborative processes in mixed-use housing projects are much more complex, and this heightened level of complexity could be better facilitated through digital collaboration.

2.2. Digital Collaborative Processes in Building and Construction

As building projects become increasingly complex, collaborative practices are becoming increasingly important in the building and construction industry [11,13] as they involve large and diverse project teams, including both professional stakeholders and end-users [53]. Despite this important role, there is less consensus in the literature on the definition of collaboration. Studies also use alternative terms for collaboration in the context of construction research and practice, such as partnership [54], team integration [55], etc. Collaboration is suggested to be a key enabler for addressing the fragmentations in housing construction [11,56], as it ensures the successful delivery of a complex building project entwined with highly effective coordination among the stakeholders across the entire value chain.

Groundwork of defining and understanding collaboration in the building and construction industry has been conducted through comprehensive empirical and theoretical developments. Earlier research defines collaboration as an inter-organisational relationship that is driven by a shared vision between all agents with shared responsibilities, risks, and rewards [57]. Schöttle and Haghsheno [57] argue in order for a new and collaborative project culture to be established, it needs to be based upon trust and transparency, as well as mutual problem-solving through interactive processes. In another closely related work, Xue and Shen [58] define collaboration in the architecture, engineering, and construction (AEC) context to be shaped through human behaviours that are highly dependent on the participants' perceptions of the shared value. In this definition, collaboration is sustained through a strong organisational culture and long-term relationships between team members, with a great emphasis on relational contracting in adverbial conflict resolution.

As the whole AEC industry is significantly influenced by digitalisation, industrialisation, and mechanisation, the effects of their resulting changes in collaboration need to be explored in relation to both the inner- and inter-organisational relationships as to how their collaboration and coordination will benefit from these transitions. In this context, digital collaboration is a key focus. Digital collaboration platforms such as web-based project management applications and network technologies have been extensively studied in the context of construction management for planning and coordination [59,60]. Although such digital platforms are effective for the exchange of project information among different participants, their common applications are limited to scheduling and workflow management suitable for specific stages such as procurement [59], and data being exchanged are mainly around 2D drawings and documents [61]. The integration or inclusion of these earlier tools in the more recent building information modelling (BIM) platforms has been effective in supporting the collaboration of the project team across different design and construction stages. The BIM approach to digital collaboration integrates structured, multidisciplinary data across a building's entire lifecycle—from planning and design to construction and operation—based on a 3D digital model of the building or infrastructure, which can be further enhanced with machine intelligence and cloud computing. BIM technologies have been found to be able to significantly improve collaborative processes, particularly in large-scale and complex building and construction projects [53,62–64], and they are increasingly adopted as the preferred method for collaboration in the industry [65,66].

It is, therefore, logical to predict that digital platforms such as BIM that can facilitate collaboration and data exchange throughout the whole project lifecycle would be equally effective in providing an enhanced collaboration environment for the delivery of complex housing developments addressing a wide range of social, environmental, and economic needs. With further technological advancement and careful implementation, such platforms would also be able to support the increasingly complex and diverse project teams, including both specialists and end-users relevant to those social challenges in housing, as discussed in the above section. However, in the current literature, while there are examples of collaborative processes associated with similarly intricate projects like specialised healthcare developments [53,67,68], there is less research about collaborative practices in complex residentials, especially mixed-use housing developments.

One of the key challenges that has emerged in the adoption of digital collaboration in construction is understanding the ways in which the necessary processes differ from the past 'status-quo' models of construction procurement and management [11]. To this end, London and Pablo [11] present a collaborative practice (CP) model that can be used to understand the processes within the building and construction industry. This model can be used as a way of understanding the network-based relationships associated with construction projects when embarking upon transformational changes in the housing sector. Our study builds upon the CP model, which was developed through five comprehensive case studies from small and medium enterprises (SMEs) active in the off-site manufacturing (OSM) housing sector in Australia. The model defines nine key elements that are essential in facilitating the adoption of new technologies and industry-wide transformational changes, as well as the accompanying collaborative practices amongst various stakeholders in complex organisational networks that are required to instigate and sustain the changes. One such element is "Leadership," which involves creating an environment conducive to change through skilful leadership. "Shared goals" represent another crucial aspect, encompassing the envisioning of compelling project objectives that address specific challenges.

The CP model also emphasises the importance of assembling a team with the appropriate "Expertise"—individuals possessing the necessary skills to contribute meaningfully to the project's success. Addressing change is another significant dimension, with the model advocating for strategies to manage change and handle potential resistance during the project's lifecycle.

"Investment" in resources is highlighted as an essential factor, suggesting the conscious allocation of resources to attract, retain, and acquire assets vital to the project's advancement. "Shared space" is recognised for its role in nurturing productive face-to-face interactions, while "Problem-solving" is underscored for its emphasis on pursuing participative, adaptable, and forward-looking solutions.

The CP model also underscores the significance of "Organizing mechanisms," emphasising the need to formalise team characteristics to sustain effective work patterns. Finally, "Technical standards" are deemed crucial for documenting and disseminating precise and accurate information, thus contributing to the overall success of collaborative endeavours.

Although the original CP model was developed based on case studies of OSM supply chains in SMEs, the generalisation and extension of the model have been shown to be applicable to the building and construction industry in general by adapting the meaningful relationships between those nine elements as they occur in other specific contexts [8]. We take this model as the basis of a theoretical framework for the data analyses and interpretation narratives because of its effectiveness in unfolding the multifaceted aspects of collaboration. Additionally, our case study and the original case studies upon which the CP model was developed share a similar level of complexity in collaboration, where they both consist of multiple networks of collaborators and organisations working together across different stages of the project. When necessary, adaptation is possible because many of the core structures and processes in these case studies are still equivalent and are applicable to a larger context [69]. In doing so, we aim to enhance the original CP model by extending its application and detailing the interrelationships between those elements as they occur in the new context, focusing on digital collaboration. This will also further improve the transferability of the model.

The next section will overview the research design and introduce the case study. Specifically, the data collection and the qualitative data analysis methods will be discussed. Section 4 will present two models established based on the original CP model with findings that emerged from our data analysis. Section 5 highlights the applicability and effectiveness of our enhanced CP model in mixed-use housing developments, followed by the conclusion.

3. Materials and Methods

This study takes a qualitative approach under the epistemology of the interpretive paradigm. The qualitative approach beholds multiple assumptions about the world. In

this realm, the interpretive paradigm postulates that the social reality is formulated by the human experience as it occurs in the social context [70,71]. The core assumption of the interpretive paradigm is that the actors in a social organisation are "knowledgeable agents" who are experts in what they do, being fully aware of their intentions, thoughts, and actions. The opportunity for emerging new concepts is then created by giving a dominant voice to these actors across all stages, from data collection and analysis to reporting of the results [69]. As for this paper, the social phenomenon is studied from the perspective of the key participants. The researchers participated in the inquiry of the actual social setting as opposed to quantitative research, where they took a more objective role [69].

3.1. Case Study Selection and Rationale

The qualitative case study in the interpretive paradigm is often based on concepts, models, and theories in the field. The case study will contribute to expanding the underlying knowledge through demonstrating a theory-oriented discussion of the findings [72]. Unlike the more dominant positivism paradigm that employs random sampling from the general population for generalisation, the case study in the interpretive paradigm needs to be unique in the sense that it fits the specific theoretical and social phenomena being studied [73]. The interpretivist believes that the outcomes of the specific case study with unique social interactions and mechanisms pertain to that particular social setting and, therefore, are not transferrable. However, ref [69] argue that it is possible to generalise from a single case study "if the case generates concepts or principles with obvious relevance to some other domain" (p. 24) because many of the core structures and processes are still equivalent and are applicable to a larger context.

The single case study approach adopted in this research is typical in built environment research, as seen in various successful examples, including [53,74], as well as in environmental behaviour research, such as [75]. The particular strength of the single case approach is that it assembles comprehensive personal knowledge [76] from multiple actors within the boundaries of a single but entire system to generate knowledge about unknown and emergent practices [75]. To ensure the transferability of the findings, the case needs to be critically selected [77], and the findings need to present a rich narrative with a thorough description of the context that allows others to decide about the adaptability of the results to other similar contexts [70]. The degree of qualitative (and quantitative) testability of the results can then be improved by developing formal and explicit prepositions when presenting the findings [69].

Based on the above understandings, the case study selected for this research is U city, commissioned by Uniting Communities (https://www.unitingcommunities.org/, accessed on 20 August 2023), a major not-for-profit organisation in social services. U city brings together multiple functions, including retirement homes, long-term specialist disability accommodations, short-stay accessible serviced apartments, social services hubs, function centres, and commercial and retail spaces, in a 20-storey vertical structure within the central business district of Adelaide, Australia. This building is very unique in providing not only a complex mixed-use program for diverse housing solutions but also in the urban setting. Being the only mixed-use housing development of its type in Australia, the building has received multiple awards for its design and innovation and for achieving excellence in supporting older people's living and creating social impact, including the Good Design Award for Social Impact in Australia's International Good Design Awards in 2020—the highest honour for design and innovation in the country. Successful mixed-use housing developments, especially "extreme" mixed-use cases such as the project being studied, are very scarce globally. Therefore, U city is an ideal case selection and provides a unique opportunity for research investigation in the specific context.

3.2. Data Gathering

The primary data have been sourced through nine semi-structured interviews with the key stakeholders from the project team who delivered U city. They each undertook

unique roles and contributed to significant decision making during the development and delivery of the project. The interviews were conducted over a two-month period in late 2019, and each interview lasted approximately one hour. Participants were recruited with the assistance of the CEO and internal project manager from Organisation Y, that commissioned and owns the building. This process has enabled us to identify and recruit senior leadership and core project team members across broad sections of the project, which is very unique and significant. The participants include the following:

The participants had distinctive roles that collectively orchestrated the progression and delivery of U city. Participant 1, the project's architect, involved in the tender process and presentation, initiated the project with great detail. Participant 2, an adept project manager, facilitated the project's diverse elements with finesse. In a central capacity, Participant 3, the project's owner (CEO of the organisation), infused the endeavour with their overarching vision and goals, providing crucial direction for the project's course. Participant 4, as the program executive for the organisation, brought invaluable insights from the not-for-profit sector, guiding the project towards its impactful outcome. Participant 4, referred to as P [4], had successfully managed large-scale infrastructure projects for the state government before accepting a position within the organisation specifically to manage this project internally. Participant 5, the client-side sustainability consultant, facilitated pivotal connections, emphasising the significance of networking in project development. Participant 6, a representative from the state government department responsible for administering one of the major grants that helped fund the project, adeptly navigated legal complexities, ensuring adherence to regulations. Participant 7, the design and construct (D&C) project manager for the construction firm, emerged as a linchpin, orchestrating intricate collaborations and ensuring seamless execution. Participant 8, a senior architect, project leader and a principal at a major international architecture firm, contributed creativity and vision, shaping the project's architectural aspects. Lastly, Participant 9, a seasoned senior mechanical engineer from a globally known firm, infused technical expertise into the project's mechanical systems.

The selection of the interviewees was determined by the case study, and it is a systematic approach as it covers representatives from all key disciplines and sections of the project delivery team. The semi-structured interview questions focused on the collaborative process in delivering U city, and prompted interviewees to consider how the collaborative process was facilitated and who led what parts of the process; the goals of their organisation/discipline in participating in the project as well as the goals of the project as a whole; whether their respective organisation/firm had the skills internally to undertake the project or whether they needed to develop new skills as a part of the project; and the specific challenges encountered when working on the project and how these were addressed by the project team. This research has placed specific emphasis on understanding the role of digital collaboration, such as but not limited to the use of BIM, in complex mixed-use housing projects. Therefore, participants were guided to specifically reflect on the use of digital technologies during the project in each main topic area of the interview.

3.3. Data Analysis

Interview data were transcribed and coded using the Gioia methodology [69]. This approach involves a systematic process that begins with the transcription of qualitative interview data, converting spoken content into written form. Subsequently, the data undergoes open coding, wherein initial categories and themes are identified, enabling a preliminary exploration of the content. Building upon these categories, axial coding is employed to organise and connect themes, illuminating the relationships between different concepts. Finally, selective coding refines and distils the identified themes, emphasising the most salient and impactful aspects of the data. The results were augmented with documented evidence from the project that was provided by the building owner, as well as desktop research into the digital technologies that were used to facilitate the collaborative processes in the project. To ensure the credibility of the results, we have also provided a

detailed description of the findings supported with selected direct quotations from the participants [70]. These detailed descriptions and sample quotations will also enable other researchers to formulate their own interpretation of the results as one of the integral steps for the qualitative research approach [78].

4. Results—Thematic Analysis

The first-order analysis involved grouping the interview data into several preliminary categories, including inter-organisational collaboration, negotiation, value management, and early project ambition setting. These participant-driven themes were further reviewed to identify the general themes related to our broad interest in the collaborative process and digital technologies. This process led to the identification of 58 themes, out of which 26 were closely related to our study's purpose.

Results from the thematic analysis are presented in Table A1 (see Appendix A). To achieve both empirical and theoretical grounding in the analysis, the participant-driven themes were devised alongside the theory-driven themes [69]. The second-order theory-driven analysis included categorising the themes based on the CP model, resulting in 26 themes mapping against the nine collaborative practice elements. In this stage, the relationships between these nine elements were also accounted for (Table A1 Column B), knowing that these relationships are not of a quantitative nature but only descriptive as emerged from the data analysis. Thus, some of the sample quotations in Column D may contain multiple themes. During the coding process, opportunities for new elements to be added to the CP model were explored. However, because each of the emergent themes aligned closely with existing elements of the CP model, no additions have been proposed to the CP model.

The results presented above demonstrate how the emergent themes from the case study align with the CP model. To further investigate the role of digital technologies in facilitating collaboration through the CP model, a second data set is presented in Table A2 (see Appendix A) that specifically focuses on the role of digital technologies within each dimension of the CP model.

5. Discussion

5.1. Core Elements of the CP Model Applied to the Case Study

The results of the analysis presented in Table A1 in the Appendix A have been abstracted and illustrated as a conceptual model (Figure 1). Figure 1 shows a core model for collaboration in complex housing developments, which enhances the original CP model by unpacking each element based on the evidence from our case study. Additionally, the model presents the interrelationships of each element with other elements, showing that each element is related to one or multiple elements of the CP model. However, these are not variables linked by direct causation nor statistical correlations; instead, they show influences in the sense that each element is not independent of other elements. To more clearly interpret the results, the following sections make references to the specific links between the different elements, as core model numbers (CM#) indicated in the model. The interrelationships between these nine elements were also accounted for, based on Table A1 Column B in the Appendix A.

5.1.1. Leadership

According to the results of the analysis, the network's leadership played a crucial role in a project's establishment and brief definition (CM1) during the collaboration in the mixed-use housing development. Defining the scope of the project and development was essential to the goal of the project in establishing an approach to balancing social, environmental, and economic priorities up-front, particularly given the focus on social outcomes (CM5—leadership and shared goals).

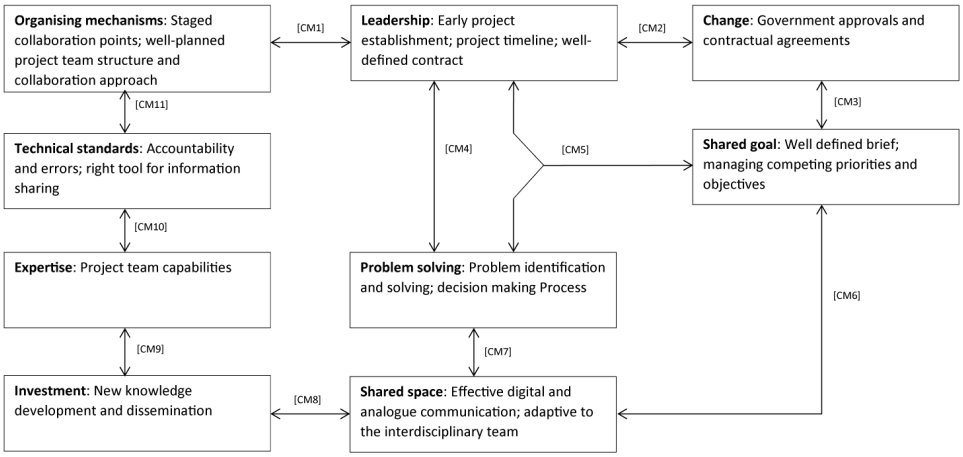

Figure 1. The core model for collaboration in complex housing developments.

Some of the leadership challenges were largely due to the unique nature of the project. One of the unique features was the project timeline. Project timelines from typical construction projects may not be appropriate for projects with complex programs, such as the "extreme" mixed-use case in this study, or with design and construction phases running simultaneously in a fast-paced environment. In our case study, for example, there were also challenges caused by too much crossover between the design and construction processes (CM4), and the rapid construction speed led to some decisions being overlooked. The complexity of the mixed-use brief led to provisional sum elements being more difficult to negotiate, which led to further changes to the brief (CM2).

> *"... the brief changed quite significantly throughout the construction cycle, throughout the D&C (design and construct) cycle, more than what a normal project would actually change. So, there was a fair bit of evolution from when we started to when we finished and what we ended up with..." [P7]*

5.1.2. Shared Goals

The leadership had a critical role in managing the competing priorities and objectives by setting clear ambitions for the project that pertained to its complexity while committing to social impact and responsiveness (CM5—leadership and shared goals). One of the interviewees explained the key shared goal of the project in bringing multiple functions together to optimise environmental, social, and economic goals:

> *"Things reduced [optimised]—so this was a pretty more environmental one—but reduced transport emissions because all of our services were being brought together in the one building and then one of the social impacts of that was ability for family members to come to visit people in this facility and then spend time, longer with them because they might take them out to a nearby café, which then had an economic benefit so it was quite connected to ability for people to live a better life in that facility and be more connected than they would if they were in housing estates that were spaced out around the place." [P5]*

The multifaceted goals and ambitions were often in conflict in this project, while different organisations within the construction cycle also had different goals that related specifically to them. The existence of clear shared goals was crucial for the actors to maintain design integrity despite changes and pairing back of elements due to the different goals of different actors (CM3). The client had a very strong vision that allowed the decision-making process to be guided by a set of principles. This strong vision and clarity of the goals are important in collaboration and for achieving outcomes; for example, they assisted in balancing social and economic outcomes during the construction phase in our case study:

> *"I used to use the term social-economic trade-off often with the Board whenever they were pushing for a greater economic return." [P3]*

The establishment of a clear vision for a unique complex project like this one, with a lack of precedent examples, was again dependent on the establishment of a strong brief. This required translating a highly layered and interconnected performance-based brief into a coordinated design. The strong commitment to the shared vision guided the decision-making process, which (as one of the actors believed) led to the project ending up being as aligned with the original design as possible:

> *"... because we've stuck to our 'guns' from start to finish." [P8]*

The importance of a well-defined brief in such projects further underlines the importance of collaboratively developing the vision for the project with a broad range of stakeholders. Expert advisory groups were established to help with brief formulation and translation to collaborate in developing a shared brief. Since the development and construction was a three to four-year journey, various workshops were organised to establish and strengthen a shared understanding of the project vision.

5.1.3. Expertise

Our data showed that designing a well-qualified team was reliant on investing in people and assets. Good coordination on-site was based on having skilled people leading the coordination process as well. This required a continuous investment in skill development to cope with the complex process of assembling a project team during the tendering process, as well as the translation of the statement of skills into action post-tendering process (CM9). Contractor selection was also based on capabilities in collaboration, innovation and track record:

> *"... So, it depends project to project who can bring the most innovative solution and who can work the most collaboratively and who actually got a track record of delivering successes in that sector..." [P8]*

5.1.4. Change

The form of contract had an important impact on the dynamics of the collaborative processes and the way the changes to the project could be managed. Competing priorities and goals were influenced in part by contractual obligations, but the relationships and collaborative culture were very important despite the different forms of contracting models (CM2).

Because of the multifaceted nature of the project and having a governmental investor, government approvals and contractual agreements played a crucial role in managing the strategies for changes. One of the funding complexities of the project due to its mixed-use nature was that the building progress was tied to financial mechanisms from governmental funding, which required government approvals and multiparty contractual processes, which is not common in most single-use developments. This was bound with complex milestone requirements and difficulty of continuity within the government contract agreements, requiring negotiation of building programs in response to funding opportunities and government housing priorities.

5.1.5. Investment

For some participants, the descriptions they gave in response to investment (Table A1) were about developing individual technical expertise rather than collaborative expertise. Investment in collaborative practices was more reliant on expertise rather than processes and mechanisms. Investment in staff training and skill development occurred to develop new knowledge and dissemination. One of the experts hinted at the lack of mechanisms for knowledge transfer as a potential area of development in construction, which can lead to a more effective understanding of the shared goals in a project (CM8):

"Making sure that knowledge from the construction transfers over into the operation of the building is something that the industry hasn't been very good at in the past. This project is challenging the ways of doing that, as I said, with looking forward to ongoing monitoring of energy and performance." [P5]

Therefore, it is noteworthy for the investors and developers to consider the cost factors and their returns related to the training and upskilling of their workforce, as well as to enable and support knowledge transfer as they adopt and implement suitable digital collaboration platforms and processes into their projects.

5.1.6. Shared Space

Our data showed that the shared space was an element that was most talked about in this project, as well as having the most involvement with the themes related to digital technologies. This relationship highlights the potential contributions of such technologies in streamlining the collaborative processes by creating an effective, shared environment, which has not been employed to its full potential. The digital platforms were used in this project as a means to enhance client communication and buy-in. Even though digital tools and databases did not completely replace informal (i.e., email) communications, the role of digital tools in augmenting and enhancing professional knowledge and skills was evident.

The tasks were divided between synchronous collaboration and asynchronous collaboration. Live collaboration was vital in the progress of the project as a way of receiving real-time feedback between working parties. The meetings essentially were centred around any event that might have a compliance issue or maybe significantly complex with, for example, the structure that needed engineering advice or external approval (CM7):

"The best way to resolve [problems] is around the table and meeting that we focus on solving a certain problem. We have to get everyone around there; it's difficult to do that kind of stuff over Aconex or over emails. You need to have brainstorming sessions and people bring ideas to the table and we test those ideas." [P8]

Another manifestation of the shared space in this project happened through the hierarchy of clash-resolving meetings. As the project progressed, newly emerged challenges would call for an additional standalone meeting to the normal weekly meetings for the stakeholders to discuss the issues.

The data showed the importance of establishing good processes early for digital collaboration and sharing of information. As highlighted by one of the interviewees:

"…the front end of your project is where you need to have things right, and that's where you set up your model, your procurement method, your requirements. That's where you need to understand what you want to deliver and what is going to take to deliver that." [P2]

There was a preference for face-to-face meetings over virtual meetings due to the effectiveness of real-time discussions, brainstorming, and problem-solving (CM7). The communication protocols would affect the quality of the collaboration. For instance, avoiding information that can lead to information loss, the importance of maintaining regular informal communication, and developing effective and customised informal collaboration as well as interpersonal communication.

5.1.7. Problem-Solving

Given the scale of the large development of this project, problem-solving was a significant challenge. The mechanisms to detect problems in various stages of the project development were not aligned with the live shared BIM model, as a lot of the problems that occurred on-site could not have been identified and managed through the BIM platform. Furthermore, the complexity of the multidisciplinary nature of the work made decision making during the construction process complicated, especially when a clash of opinions or a difficult issue emerged. The problems would be managed through the solution meetings where a response to a particular problem had been formulated before being issued through

the BIM platform to the relevant stakeholders. However, not all the documentation would be embedded in the BIM model, leading to the absence of some information and affecting the decision-making and problem-solving processes (CM7).

The data also highlighted the importance of having experience with complex construction from the client side for effective problem-solving; for example, the influential role of the client-side project manager in facilitating collaborative decision making was evident in our data (CM4).

5.1.8. Organising Mechanisms

The organising mechanism was streamlined through the design team and the design review meetings, as well as processes to establish a collaborative culture around the ambition of the building. These interactions were effective due to the prior experience of the design and engineering teams working together.

From the perspective of the project team's structure, it involved a multistaged and hierarchical leadership system with leadership and other key roles shifting across the project's lifecycle (CM1). For example, during the design stage, another architect had more of a design role, and the project architect focused more on the management side, making sure the project was meeting the desired goals, while the other architect was more focused on the design. During site delivery, the project architect also shifted to the leadership role with the team's support.

5.1.9. Technical Standards

The BIM model was of great value for various stakeholders, especially the facilities manager, for error and clash detection. However, the BIM model was not used to its full potential. For instance, while the architect and engineer teams would work together on a shared platform, the energy modelling was undertaken offline, making BIM a modelling outcome rather than an iterative design tool. There were obstacles to the accessibility of the BIM model to all the relevant stakeholders due to the lack of effective organising rules for information sharing, such as those for addressing privacy and IP concerns. At points, information exchange, model sharing, and coordination were challenging because the BIM model did not capture or update some of the consultant's reports, leading to the information being lost (CM11).

A need for governance structures for information management and document sharing was another frequent theme in our data analysis for effective process management and communication for collaboration. The project involved ongoing reporting, management of government contracts, and on-demand data in public–private partnerships due to continuous performance monitoring.

Although BIM as a collaborative platform innately involves the active participation of the various stakeholders, despite using a BIM model for this project, not all stakeholders shared the same understanding. While the more technical teams of designs and engineers would actively use and contribute to the model, the less technical teams had a lower share in contributing to and accessing the model and were also less aware of it (CM10). This is perhaps due to the fact that BIM was used primarily as a technical design tool rather than a collaborative tool on parts of this project.

The future life of the BIM model was reliant on the ownership of the model:

> *"The intent is that the model is the client's property at the end of the day because they've paid all the money for this to be done. Does the client do anything with it? I have not seen it yet. I think it sits there somewhere. The unfortunate reality also is with software packages being changed every year and you're not getting that backflow software compatibility currently done." [P9]*

In summary, the analyses show that collaboration in mixed-use housing developments requires early project establishment with a well-defined contract and brief to manage conflicting and competing priorities and objectives. This early vision for the leadership is important to tackle the complexity of the project by enabling a practical collaborative

approach through setting staged collaboration points and a well-planned project team structure. It is also essential for problem identification in the decision-making process while meeting competing demands when public sector and government bodies are involved. Developing the right tool for information sharing in a project with multiple stakeholders and teams involved is imperative for accountability and clash management.

The results also highlight the importance of the investment in enhancing the capabilities of the project team as well as developing and disseminating new knowledge. The overarching element is enacting a shared space with effective digital (and conventional analogue) communication mechanisms adaptive to the interdisciplinary teams. This makes it challenging to balance out the competing needs, contrasting demands, complex decision making, and keeping the goals and objectives consistent in the building and construction discourse.

5.2. Digital Collaboration in Mixed-Use Housing Developments

Focusing on digital collaboration from the analyses, several insights have arisen from the results, as discussed in Section 4 and Table A1. Additionally, the narrative presented below is supported by the sample quotations, as shown in Table A2. This narrative is based on not only the initial themes of the original CP model but also a critical integration of the new themes specific to digital collaboration, as emerged from the interviews, which were largely related to the barriers or challenges of digital collaboration.

The data suggested that in digital collaboration, allowing more time in the early stages of a complex project to include a well-defined digital collaboration plan is essential to effectively manage changes, especially those related to the brief during the design and construction phases (leadership and change). This case study did not enact an early digital collaboration plan, and the stakeholders believed the existence of such a plan could have led to better delivery of the complex milestones across the whole development process (change and shared goals). The digital literacy of the stakeholders was not at the same level across various teams, with the majority of the digital processes being managed and conducted by the design and engineering teams (expertise). While digital literacy was not commonly expected from all stakeholders, especially non-expert stakeholders such as the client, the case study showed that the client's familiarity with the digital processes evolved and increased during the project development, and bringing the client on board early to invest in digital skills and technologies (e.g., in the project investment plan) would have enhanced the potential and success of developing and implementing complex digital solutions (expertise and investments).

The project made use of various digital technologies and approaches to improve the shared understanding of the building (shared goals, problem-solving, and shared space). Digital model sharing also helped with the design and construction accuracy as well as allowed real-time viewing and rectification of emerging problems (problem-solving). Additionally, the integration of both digital and analogue prototyping tools assisted in communication, especially between the professional teams and the client. The hybrid approach between the digital and the analogue methods was widely adopted in the project; for example, testing of various building systems and interfaces was conducted physically to ensure compatibility before construction, while computer simulation for analysis of spaces was also carried out to ensure compliance with building codes and performance expectations. Within the digital approach, the different tools and media were also utilised differently as needed; for example, 2D tools such as those for spatial design with 2D mark-ups enabled a faster workflow, especially during the conceptual design phases before the design model was realised in the 3D BIM platform. At the same time, not all building information embedded within the BIM model was in 3D (organising mechanisms and technical standards).

The main themes emerging under this focus have been abstracted in a sub-model of digital collaboration, presented in Figure 2. This new model is grounded on and extended

from the core CP model, as shown in Figure 1, but focuses on digital collaboration; therefore, the main interrelationships between elements have been inherited.

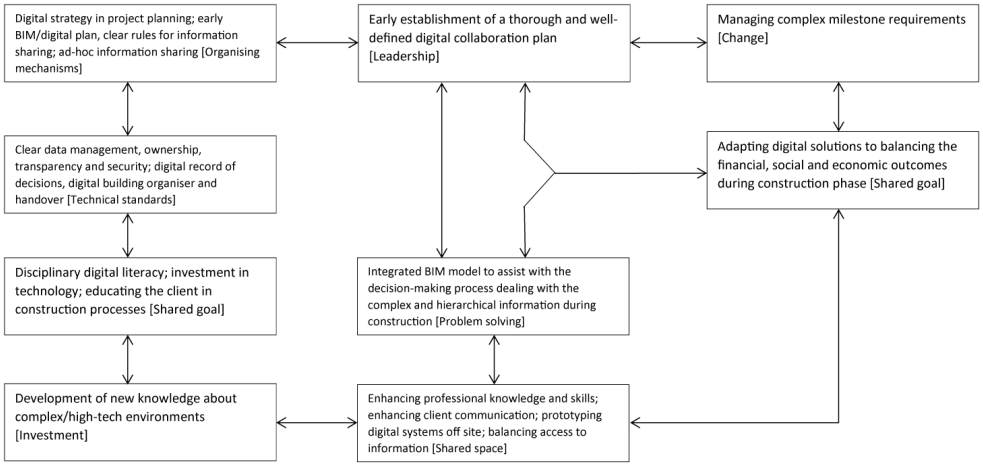

Figure 2. The sub-model of digital collaboration in mixed-use housing developments.

6. Conclusions

Mixed-use housing developments present significant potential to address various social, environmental, and economic challenges. This research has exploited a unique opportunity for investigating the topic through a successful case study of an "extreme" mixed-use program that is scarce globally, with rare access to key stakeholders who have contributed to critical decision making during the delivery of the project. Our study emphasises the importance of understanding and accommodating the complex collaborative processes, especially those related to digital collaboration in such developments, by introducing and enhancing the original CP model through the analyses of the case study. The findings from our empirical query have been interpreted and discussed firstly in terms of the core elements of the CP model, followed by a specific elaboration centred on digital collaboration. These understandings have been incorporated and resulted in two models: a core model on collaborative processes and a sub-model specifically on digital collaboration, both in the context of mixed-use housing developments. Building on the original CP model, our study has a number of contributions by (i) contextualising the CP elements within a new context of digital collaboration, (ii) identifying and detailing new relationships between these elements as evident from the case study, while extending the CP model; (iii) leveraging a more holistic understanding of the processes in digital collaboration by recognising and exploring multiple elements as a whole, which has rarely been studied in such an integrated way in the past research. Therefore, our research contributes to the enhancement of academic research areas of digital collaboration and collaborative processes in the AEC industry more broadly. The investigation of our case study has also shed light on the future technology development and adoption of digital collaboration. Given one of the main shortcomings of current BIM adoption is the lack of effective engagement of all stakeholders across the project, future digital collaboration development and adoption need to motivate and involve all stakeholders early on. As shown in our case study, the successful adoption of digital collaboration seems to embrace and implement a BIM/digital plan from an early project stage. It also requires a complementary set of digital tools that aid collaboration and communication besides BIM data integration and sharing. This is especially important for non-expert stakeholders such as the client. The digital plan then requires to accommodate different stakeholders' needs and technical competencies. An integrated plan for digital collaboration also needs to include strategies for balancing synchronous and asynchronous communications as well as balancing digital, analogue and hybrid information and approaches suitable for specific projects and project teams.

In addition, the present study provides insight to building and construction professionals, as well as investors and building developers, to allow them to extract tangible strategies for investing, planning, and implementing digital collaboration, as outlined in the developed models (Figures 1 and 2). These strategies are useful for mixed-use housing developments as well as other complex building and construction projects, as the applicability of this study has been supported by providing rich descriptions of "portable principles" [69] that can be transferred to different contexts. In accomplishing the study's stated aim, as outlined Section 1, we have meticulously unravelled the intricacies of digital collaboration. In summary, several strategies pertaining to digital collaboration, as perceived by the stakeholders, are highlighted below:

- Establishment of a clear and thorough digital collaboration plan in the early phases of the project, bringing different stakeholders on board;
- Integration of different technologies as needed to aid collaboration and communication besides BIM (especially for non-expert stakeholders such as the client)—a potential technological solution for digital collaboration is to consider a complementary toolset centred on, but not limited to, BIM that facilitates collaboration and enhances communication and visualisation, according to the technical needs and competency of different stakeholders;
- Utilisation of digital technologies to engage a wide range of stakeholders throughout the project's development and delivery. This should be coupled with the provision of suitable training, upskilling opportunities, and pertinent knowledge transfer activities.

These key findings align with those of previous studies on digital collaboration in the AEC sector, emphasising the importance of early stakeholder engagement [79,80]. However, the unique contribution of this study is combining and investigating multiple factors within the CP model in a unified context. This approach offers a valuable opportunity to gain a comprehensive understanding of the influential factors and their relationship to the overall mechanisms involved. Through the case study, this research thus provides important learnings about the phenomena centred on digital collaboration in mixed-use housing developments that are emergent and little-understood. While we acknowledge the limitations in employing one single case study, the research methodology makes full use of the unique case study, a rare and award-winning design for social impact, which exemplifies mixed-use housing developments in addressing social challenges. The case study has provided access to a complex network of collaborators and disciplines working together in the development and delivery of U city for the purpose and scope of our research. For future extensions, firstly, a deeper development of the sub-model where both the benefits and constraints of digital collaboration could emerge will be undertaken; for example, one potential constraint might mean unevenness in collaborative capacity when a stakeholder does not have adequate expertise, and details and varying contexts at such level will be explored in the model to further enhance the development. Secondly, a mixed-method approach will be considered to extend the methodology by incorporating quantitative techniques and also utilising a larger sample of stakeholders by expanding the participant recruitment beyond the initial leadership and core stakeholder group. Further, although a number of the participants are end-users of the building, the current study did not include the main end-user group—the occupants housed within the building. During our research data collection, access to this general end-user group was not available as the building was still in the final stage of completion. Occupants' buy-in of digital collaborative processes is an important topic and will be considered through a post-occupancy follow-up study. Finally, future research can also explore new emerging technological advancements as they emerge in addressing the complex housing project delivery and collaboration for optimising social impacts. The developed core model and sub-model for digital collaboration from the current study can also be augmented and benchmarked through more empirical research when similar mixed-use housing developments with a similar scale and calibre emerge. It is worth noting that the majority of data collection in this study was conducted before the COVID-19 pandemic. The recent

wider adoption and acceptance of remote working across different industries may have changed some stakeholders' perceptions about digital collaboration. Nevertheless, they have further supported the importance of digital collaboration, not only for the building and construction sector but across all sectors of society. Thus, the potential of this study in unpacking the digital collaboration practices is of further importance as the developed models contribute to a better understanding of the mechanism of and the support for this emerging digital working environment post-COVID.

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Appendix A

Table A1. Theory-driven analyses, mapping the themes with the CP model.

Key Elements in the CP Model	Interrelation-Ships Within the CP Model	Themes Related to (Collaboration on Mixed-Use Housing Developments)	Sample Quotes from the Interview
Column (A)	**Column (B)**	**Column (C)**	**Column (D)**
Leadership	Change, Problem-solving, Organising mechanisms, Shared goals	Project establishment (pre-consultants)	*If we were to build specialist disability accommodation, would the market support high-rise living for people with a disability? We tested that with groups like ParaQuad and Multiple Sclerosis, MS and a few others as well, so we tested that more broadly with what we saw was the potential market for that type of accommodation.* [P4 (P refers to "participant")]
		Project timelines (from typical construction projects and may not be appropriate for projects with complex programs)	*Make your BIM model if you're going to use it as a requirement from the start.* *Your ability to influence a project against cost at the start of the inception is huge. The little cost. As you go through the project, that flips, and your ability to influence cost, sorry, to influence outcomes, so the cost goes through the roof. So, I think, it's the front end of the project where you need to be. I've been involved in plenty that have turned pear-shaped.* [P2]
		Impact of the form of contract on the process	*The design construct can be really good, but I felt like, as I said before, you need more time to test things, and if you're designing something for an end-user that is so bespoke, I think, we needed more time, really, to explore that, and you can design to make it work within that contract.* [P1]

Table A1. *Cont.*

Key Elements in the CP Model	Interrelation-Ships Within the CP Model	Themes Related to (Collaboration on Mixed-Use Housing Developments)	Sample Quotes from the Interview
Column (A)	**Column (B)**	**Column (C)**	**Column (D)**
Shared goals	Shared space, Change, Leadership	Managing competing priorities and objectives (by setting clear ambitions for the project)	*Different organisations within the construction cycle have got different goals that relate specifically to them. So, from being the main contractor, our goal is to finish on time, provide a suitable level of quality and be able to make sure that it's profitable. At the same time, we specifically targeted (this project) because of its quite broad range of services, and we wanted to be able to demonstrate our skill set and ability to the market in Case A to show what we can do. So, one of our goals was to be able showcase what we can do, and I think we've done that. But in terms of the project itself, that had a whole number of different social goals. We have nick-named the building, Radically Mixed Use, because of its range of services.* [P9]
		Brief development (establishing a strong brief for complex projects)	*The key is to have a strong brief that the contractor tenders on so that we make sure that those key architectural statements or whatever planning statements are locked down and that it's black and white. You either achieve it or you don't achieve it. I've been doing D&C projects since pretty much over the last 15 years since I began working here. So, it's really that experience in knowing what needs to go in the brief and what can be left out because there are certain things, they make the project and then there's other things that you can say okay it can be substituted to something else but still achieve an outcome. So, it's really that understanding of what's really important and what you can give and take.* [P8]
		Collaborative brief development	*There was a steering committee that was established of some key advisors to the Board, and we used the expertise that came with that group, quite a diverse group of people, to test those changes in scope and to make representation to the Board through that steering committee.* [P4]
		Finance mechanisms (remain largely inflexible despite the ambitions of the project)	*The finance industry really doesn't go down that path. They need a very clear perspective of what it is you're trying to do so they can make a reasonable assessment around the risk profile for them, and that was one area where I was asked to assist with putting that structure into that collaboration piece as well.* [P4]
Expertise	Investment, Technical standards	Project team capabilities	*As the D&C contractor, you choose how you want to run your job. Your delivery method, both design, procurement and construction, so we make it clear at the time when we go out to tender, when we're tendering each of those services packages, that we're going to be running our services modelling, using them in 3D, and that's going to be a prerequisite on this job. Now, if they can't do that, they won't price for us, but again, the way that we run our procurement model is that it's not just about dollars. It's about actually getting the right contractor for the job. It makes our life easier, and it gives a better product. So our tender field, each one of those trades that we would have gone out to, will do that any day of the week.* [P7]

Table A1. *Cont.*

Key Elements in the CP Model	Interrelation-Ships Within the CP Model	Themes Related to (Collaboration on Mixed-Use Housing Developments)	Sample Quotes from the Interview
Column (A)	**Column (B)**	**Column (C)**	**Column (D)**
Change	Shared goal, Leadership, Shared goal	Government approvals and contractual agreements	*I think it would be good if there was a framework around it, how you create that for individual—for unusual projects, I don't know. So, I do feel like the contract management framework tells me that I need to do a contract management plan. And it tells me when I need to contract management reports, and it gives me guidance to say you need to do these things. Because I can apply it to most contracts or all contracts, really. It's actually all about—like, something like a build like this is, maybe it's with the wrong department. You know, SAHT is not a department that builds big buildings. You know, DPTI is maybe. Maybe there sort of should be some more consideration when—it was just a—it was a strange thing that we were given this funding to pay for something that doesn't sit with our minister.* [P6]
Investments	Shared space, Expertise	New knowledge development and dissemination	*(The knowledge generated about the project is) in-house really. So, built in our team that's actually collaborated and put all of that together, is where it sits. Yes, we have a brief, in terms of where that assistive tech is, which is a performance brief, which is pretty much this is what we want. We've really taken that into a detailed spec and then a fabrication process of let's get all of this theory to work. So design meeting minutes, assisted tech workshops, all of that is pretty much where we are all of that.* [P7]
Shared space	Investment, Problem-solving, Shared goal	Digital tools (utilised as a way of creating a shared environment)	*I mean, we're now looking at tools which are counting carbon as part of what we're modelling. So, we'll be able to understand how much carbon and all that sort of stuff. We've got the Green Star sustainability rating tools that are connected with that. There's all sorts of things, tools that you can use, digital tools to inform the design around site lines and all these different things that I think we've been through before.* *But again, I feel like a lot of it is intuitive, but it's just evidencing what you're doing. So, all they're doing is really building consensus and making the information that you're providing a much higher quality set of drawings or whatever it might be. But at the same time, you can't neglect the fact that you've got to be able to talk about it. You've got to build a relationship around these things, especially when someone who's going to be using the building for 50 years or 100 years or something.* [P1]
		(Enabling) real-time collaboration	*(Real-time collaboration) is something that could always be done better because there is the time delay. On some projects, we will go into the architect's office, normally if we are part of the design team, and we will be working with them on butter paper if they are sketching up things and we will be providing live advice, and that's obviously better and quicker, whereas in this case, we were seeing things after the decisions had been made and then the design was forming and then we were commenting. But it was quite attritive so we got a chance to comment on lots of times.* [P5]

Table A1. *Cont.*

Key Elements in the CP Model	Interrelation-Ships Within the CP Model	Themes Related to (Collaboration on Mixed-Use Housing Developments)	Sample Quotes from the Interview
Column (A)	**Column (B)**	**Column (C)**	**Column (D)**
		Analogue/digital prototyping	*We actually built, off-site, a prototype of the room controller and did physical connections with each one of those systems off-site before we started construction to verify that our academic theory design was going to work. And then, when we actually started on-site, we built a prototype room, and the prototype room went really well. So it was good.* [P7]
		Communication	*We used Aconnex for the project, (it's a) really good tool. You can track things three years down the track as long as it's used correctly. One maybe thing to avoid, multiple emails—I think communication could be—sometimes everyone has been copied in, so you constantly get reminders. But that's personal management. That's not to do with the collaboration. It's good on the collaboration side of things. You get incoming information. It's how you then process that communication.* [P2]
		Digital vs. face-to-face communication	*The best was to resolve (issues) is around the table and meeting that we focus on solving a certain problem and have to get everyone around there, and it's difficult to do that kind of stuff over Aconex or over emails. You need to have brainstorming sessions, and people bring ideas to the table, and we test those ideas.* [P9]
		2D and 3D work environments	*Two-dimensional layout first to just get an understanding of, can this be done. Two-dimensional layout about but also thinking three-dimensionally. It is faster way of working. Because if you had to then look at it in a three-dimensional way, we would then have to get our BIM modellers engaged to first explain what's required. They would then implement it into the model. They would then save the model. We would then take that model back, and then we would share it. If that's not the right solution, we would then have to go back to the BIM modellers and then redo it again before we then went back.* [P9]
Problem-solving	Leadership, Shared space	Problem identification and solving	*BIM doesn't control what somebody does on-site, but you would think that everything is designed and understood and laid out in such a way that you're not making those last-minute decisions, you know. We were dropping bulkheads to run services because somebody didn't think about something. The box within the mechanical pipework was delivered 50 mm deeper than what they allowed for in their original drawing because the model changed.* [P2]
		Decision making	*Where documentation is not in the live collaborative model space, it needs to be identified such that everyone is aware of the documentation and live spaces for these items. Then, there's items which aren't which need to be then looked at once it's done.* [P9]
Organising mechanisms	Technical standards, Leadership	Staged collaboration points	*We were always presenting back to our consultants as well to make sure they knew what we were talking about, but also what the design intent was. It's not always the case. Sometimes it's pretty informal, and you, sort of, just—but basically—I mean, the Revit model and the coordination of that is your main connection to your consultants and getting spatial on that. In the initial phases, they're not digital anyway. They're probably giving you mark-ups or a spreadsheet or something.* [P1]

Table A1. *Cont.*

Key Elements in the CP Model	Interrelation-Ships Within the CP Model	Themes Related to (Collaboration on Mixed-Use Housing Developments)	Sample Quotes from the Interview
Column (A)	**Column (B)**	**Column (C)**	**Column (D)**
		Planning for digital collaboration (absence of a plan for digital collaboration)	*I think it was quite easy for us to get the information. There was definitely times when we had asked for information that had been circulated, and we weren't included on the—because Aconex was used by the rest of the project team, I'm pretty sure, and we wouldn't have been included, so then we would have to be emailed separately. So, some of that would have made things easier if we had been included on the design team's communications.* [P5]
		Project team structure	*More often than not, it was me, but again, at different stages of the project, we had different (leaders). For instance, during the design stage, (another architect) had more of that role, and I did more of the management side of things, making sure that we were doing everything that we needed to do, and he was focusing on the design. During site delivery, I had pretty much the leadership role through that with support of the team.* [P8]
Technical standards	Expertise, Investment	Digital information sharing	*The outcomes from the modelling could have been better if they were shared, but it is not commonly done, I suppose. The engineers and architects tend to work quite well together, collaboratively sharing the models. But the energy modelling tends to be done more just behind closed doors.* [P5]
		BIM Usefulness postconstruction	*(Government) do tend to need things more* ad hoc *than quarterly reporting allows, but I generally have to just use quarterly reporting because that's how everywhere seems to provide you with their reporting. Real-time data is always good, and we've got our own dashboards for piles of different things that we have. We use Power BI predominantly, where we collect all of the data warehouses, access databases, have them all feeding through the one source so we can run our own kind of reports.* [P6]
		Duplication of models	*We did do a little bit of our own modelling to support our advice, yeah. Yeah, but they were then prepared separately to the design team based on the documentation.* [P5]
		BIM as a collaborative tool	*I would say that there would be one (architectural) model. There could have been some rogue models, and I think, perhaps the façade might have been a separate model, just because of the complexities of how much detail was in it, and so, that gets separated out. I think, early on as well, we tried to script things using Rhino, and it's better to try and import from Rhino and then just rap it in Revit.* [P1]
		Accountability and errors	*(The final model) was very close. Look, at the end of the day, there's always human behaviour. So, someone will always put something in the wrong spot or move it 10 mil out, but nine times out of ten, it needs to be in that spot for whatever reason to make sure that if we're talking ceiling grid, everything is centred, everything is in the setout that it was planned to be. Otherwise it wouldn't fit, otherwise it wouldn't be there. So, look, there's definitely instances where you've got construction tolerance, and things are going to be out here and there, but a lot of our guys fabricate off of their model.* [P7]

Table A2. Digital collaboration themes supported with sample quotations.

Key Elements in the CP Model (A)	Sample Quotes from the Interview Related to Digital Collaboration on Mixed-Use Housing Developments
Leadership	*That's a separate point. But if we were to collaborate, yes, time would be better, and also, I think helping understand the client better, of course, the time it takes to digitally collaborate as well. You know what the end product needs to be, so if the client goes, "I don't really care what the end product is. I don't want the model at the end of the day, I just want my building built as fast as I can."* [P9]
Shared goals	*Different organisations within the construction cycle have got different goals that relate specifically to them. So from being the main contractor, our goal is to finish on time, provide a suitable level of quality and be able to make sure that it's profitable. At the same time, we specifically targeted (this project) because of its quite broad range of services, and we wanted to be able to demonstrate our skill set and ability to the market in Adelaide to show what we can do. So one of our goals was to be able showcase what we can do, and I think we've done that. But in terms of the project itself, that had a whole number of different social goals. We have nick-named the building, Radically Mixed Use, because of its range of services.* [P9]
Expertise	*If you're just doing a standard floor plate, you just get a very simple stick diagram, and your member is going one direction at this date, and therefore, they price their work based on that. You can still design a building without it being full digital. When you're in a competitive environment, having a fee for more of your consultants to model absolutely everything would be putting you out of contention. People don't understand the value in that and are not asking for that. They're just asking for a building. It does happen on projects; don't get me wrong. There are consultants that do it, and the value is that from the get-go, you've got the information in 3D, and there's no risk of misinterpretation, presumably, because they're modelling what they know, and then the next just similar models to what they know, and then it's really the architect's role to coordinate that.* [P1]
	I think everybody always gets better, so the more projects you do in the model, the better you're at managing it, the better you're working in it. So I definitely think that everybody got a lot better, everyone continues to improve. So from a 3D model perspective, I think we did a pretty good job. There's a few lessons learnt, but nothing too considerable. [P7]
Change	*There was also several lots of funding that were offered into the building. It was about meeting milestones, both time and quality, at various stages throughout to ensure that the funding grants came to (the client). And then, the other thing was making sure each space was adequate and fulfilled the requirements. So, I guess, when you've got so many parameters to meet in one building, you're obviously always conscious of budget, but, I think, budget and time probably sit over here in a bit of a parallel with, we want to do that, and we need to have an overall exposure for our client, we need to understand what the cost is going to be, but there's no point in having a building finish on time and on budget if all the other objectives haven't been met.* [P2]
Investments	*In terms of investing in staff, we did upskill quite a few of our staff in terms of especially around the disability accommodation and the technology piece.* [P8]
Shared space	*I think explaining it in a three-dimensional way gives perspective because people might not always think in 3D. When you're looking at a 2D plan, you're very much reliant on your experience to be able to visualise that and what's happening in 3D. And that's sometimes really hard when you've got multiple things in your mind, and you're looking at something, and someone is trying to explain this to you, and you really can't focus much. Showing it through the snapshot would get everyone engaged, and then would be able to understand what it is. In 2D, it could look like a small circle, but in 3D, it could look like a massively large cylinder with—so people understand the views of it.* [P9]
	There will be hand sketches initially, but then supported by Revit and Rhino massing. Producing imagery and then trying to align any physical model with the digital model at the same time so that we can always take a physical model to a presentation, and then have the digital model that we're explaining in the presentation, looking the same. So, even when we did the tender presentation, we had a physical model when we went in there because we wanted to introduce some of the ideas that we wanted to show that worked physically, and it was about making it more analogue. And then some of the workshop tools, like the design board game thing, it's about trying to make it more analogue for them because they weren't really engaging in that sort of thing, and we didn't have VR goggles to chuck them in spaces and stuff. And we can show them elevations, show them lots and lots of 3Ds, but just be able to be more tactile, and stuff is sometimes more valuable in that phase. [P1]

Table A2. *Cont.*

Key Elements in the CP Model (A)	Sample Quotes from the Interview Related to Digital Collaboration on Mixed-Use Housing Developments
	Every time, there's technology problems. That's generally the biggest obstacle to it, either someone doesn't know how to dial in, or they miss the password or the code or whatever, or the network is down when they have to do a video conference. So if there's a problem, more often than not, it will be from technology side rather than the user side. [P8]
	Where documentation is not in the live collaborative model space, it needs to be identified such that everyone is aware of the documentation and live spaces for these items. Then, there's items which aren't which need to be then looked at once it's done. [P9]
Problem-solving	*BIM doesn't control what somebody does on-site, but you would think that everything is designed and understood and laid out in such a way that you're not making those last-minute decisions, you know. We were dropping bulkheads to run services because somebody didn't think about something. The box within the mechanical pipework was delivered 50 mm deeper than what they allowed for in their original drawing because the model changed.* [P2]
Organising mechanisms	*So the lead BIM modeller at the end of the week would effectively run through a clash detection or a system. That report would get distributed across to the modellers and the engineers, who would then have to look down and say, "Okay, who is going to cave in?" Someone needs to move. Yourself, yourself, or yourself.* [P9]
	I could see (BIM) being a big benefit to the FM, the facilities manager. If your facilities manager has got a model that they can access, it's got every FCU, every leaf, every motor, which spits out into another sheet which says it was installed and it was serviced, then there's a problem with that one, it's been replaced there. I mean, that's understanding access, understanding exactly where it is. At the moment, I've got fire sprinklers out the front of that building running along Franklin Street, that there was a last-minute change that the builder made. I don't know why. They were never on any drawing. All of a sudden, I've got fire sprinklers sat down through the front soffit. I don't know where they're fed from. I don't know how to isolate them. I don't know anything. [P2]
Technical standards	*So the architects would have had a digital model, which would—I can't recall exactly what they used, but they had digital models and then collaborated with the engineers so that everything was modelled in 3D. The engineers also prepared specific modelling to do with sustainability, so there was energy models, and they did some daylight modelling.* [P5]

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