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Intergenerational cooperation and co-creation in public space design assisted by Virtual Reality (VR) environments

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Abstract

The world's ageing population presents both challenges and new opportunities for urban design, particularly in high-density cities like Hong Kong. This study investigates intergenerational cooperation in the co-design of urban public spaces, assisted by Virtual Reality (VR) environments. Through a series of workshops inviting youth, university students, middle-aged adults, and older residents to work in small teams, we documented their interactive behaviours and observed how the involvement of different age groups may influence the cooperative process and design outcomes, especially when VR tools were involved. Our findings shed light on several key aspects. First, how work engagement levels differ based on highly-, moderately-, and non- intergenerational groups. Second, observable patterns of common task-role distribution between age groups within a self-organised collaborative process. Thirdly, the various types of social participation, from cooperative, associative to solitary, emerged as a consequence of such interactions. Finally, from the co-created public space designs, any transformational and transactional values that arise were discussed. The study contributes to ways in facilitating more age-friendly approaches in urban design, especially in face of digital transition, and highlights the importance of intergenerational cooperation in design processes so as to create more inclusive environments.

Keywords Intergenerational Collaboration, Community Engagement, Virtual Reality (VR), Public Space Design, Participatory Design

1 Introduction

The world's population aged 60 + is expected to double by 2050 and Hong Kong is projected to rank first (WEF, 2023; WHO, 2022). The HKSAR government (2015) has put forth a city-wide 'ageing-in-place' policy, delivering residential care services (RCS) and community care services (CCS). One of the main challenges is to foster supportive environments that can cater the varying needs of different age groups, while encouraging intergenerational communication and collaboration (HKFYG, 2019).

In the built environment, the design of intergenerational spaces and activities can be better supported through cooperative design methods, where stakeholders from different age groups come together to generate shared ideas (Fang et al., 2023). While urban design aims to create accessible environments for all ages, youth and older adults are often excluded from decisions about the built environment (Mawasi et al., 2022). More research is needed on how to effectively involve these groups in the co-design process. Also, urban integration with intergenerational public space design remains underexplored (Nelischer & Loukaitou-Sideris, 2023; Wendel et al., 2022).

In the context of digital participation in urban design, the potential and challenges of using digital technologies to assist intergenerational cooperation suggests a need

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for further research, especially in understanding how people from different age groups work together and with digital tools (Chowdhury and Schnabel, 2019). There have been increasing efforts to study how Virtual Reality (VR) environments may assist 'design communication and participation of laypeople', distributing tasks according to varying skills so as to achieve a virtual participatory urban design process (Chowdhury and Schnabel, 2019) (Fig. 1). VR is defined to be the use of computer simulated 3D environments that 'may or may not aim for complete immersion', with the goal to share a spatial experience (VRS, 2017).

The study aims to explore intergenerational participation in urban design, especially in face of increased digitalisation. The novelty of our work lies in an integrated exploration from aspects of work engagement, task-role distribution, social participation, and design outputs. It questions current practices of co-design, specifically: *"how to enhance the quality of intergenerational participation in public space design through a better understanding of participants' cooperation and co-creation assisted by VR environments?"*.

The objectives are 1) to observe how intergenerational groups cooperate and influence design participation; 2) to understand how different age groups interact with VR tools; and 3) to examine patterns and differences in their public space design outputs. The study hopes to provoke deeper reflections on how the future of an ageing population may serve or be served, and ways in which our modes of architectural production would change through digital collaboration.

2 Literature Review

2.1 Intergenerational Programming and Active Ageing

Intergenerational study is an interdisciplinary field that encompasses child and adult development, psychology, education, and gerontology; it acts as the basis for developing intergenerational programs in public services (Larkin & Newman, 1997). Intergenerational programming can benefit neighbourhood trust, sense of belonging, circle of care, reciprocity, and sustainable community (Jarrott, 2021). These programs can include a variety of activities, such as recreational, educational, public service, health promotion, and personal development (Ames & Youatt, 1994).

Intergenerational programming integrates principles of active learning and active ageing for both youth and older adults, aiming to elevate each other's lives. Active ageing, a framework introduced by the World Health Organisation (2002), is based on three pillars: participation, health, and security. This concept challenges the notion that older adults are passive recipients of public services, instead emphasising their role as active members of society, which is a valuable asset for all. The Hong Kong Institute of Volunteers (2016) summarised six objectives to implement these pillars, including the

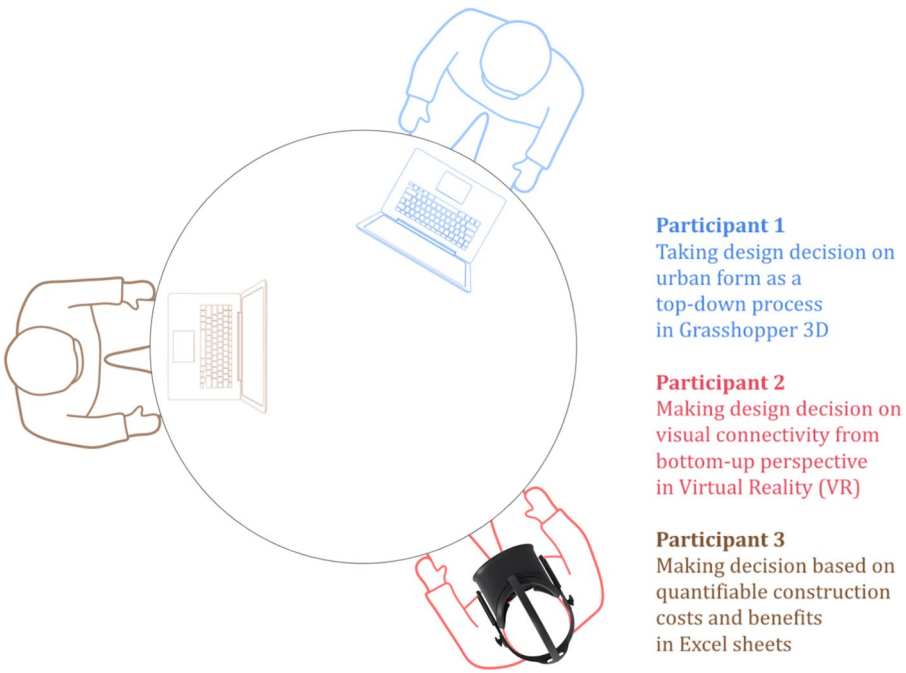

Fig. 1 A seating plan adopted from Chowdhury and Schnabel's (2019) study that looked at how simulated environments and VR may assist design participation of laypeople

joy of volunteering, discovering new passions, lifelong learning, opportunities to perform abilities at work, and a new domesticity. Particularly, the last point highlights the importance of designing living spaces that are inclusive and accessible, as well as considering the activities that can take place in the domestic sphere.

Recent developments in co-living or ageing-in-place projects with a focus on shared-sites and transgenerational design exemplify how daily informal encounters and planned activities can empower both youth and older adults (Jarrott et al., 2008). These interactions encourage mutual learning, improve dispositions towards different age groups, provide needed services, share resources, increase cost saving, and overall enhance Quality of Life (QoL). To achieve a higher degree of community empowerment, intergenerational activities should be cooperative in nature, based on the public engagement ladder (Fig. 2):

- education – an active, expanded, informal education to broaden one's intellectual horizon;
- public service – to serve or be served by shared activities and services that are:

  self-directional and let (older) adults feel relevant and/or useful;

  explorative and help children and youth to persist in self-chosen tasks.

- health promotion – body and mental health and wellbeing;
- personal development – that results in social mobility (Ames & Youatt, 1994).

This framework helps to guide the design of engagement programs that can bring social harmony, cohesion, reciprocal understanding and mutual growth between and within communities of different generations.

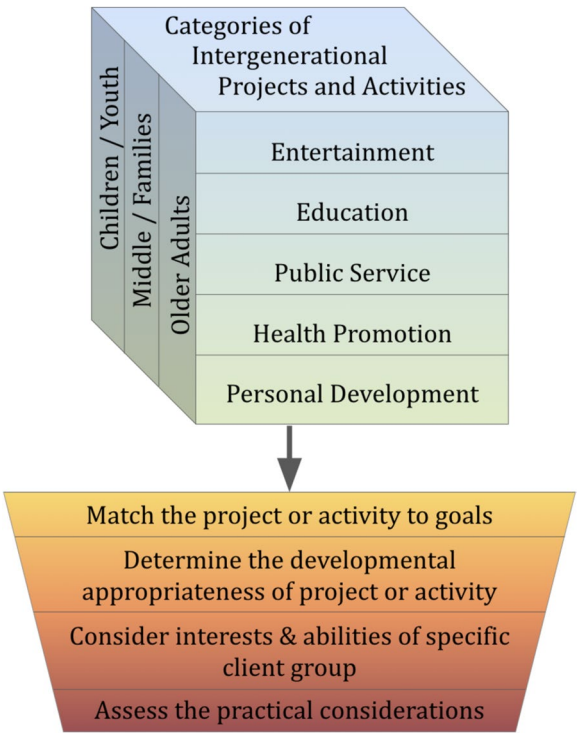

Fig. 2 A model for 'selecting appropriate intergenerational education and service activities' adopted from Ames and Youatt's (1994) study

2.2 Third Places in Virtual Reality: Precedents

Within community engagement, virtual technologies have emerged as a useful engagement tool to minimise generational segregation caused by the digital divide. They can build up social connectedness through procedural storytelling and function as a community hub – Third Places (Appel, 2022). Third Places are community spaces characterised by a playful mood and expanded possibilities. By facilitating informal encounters, spontaneous conversations, and pure sociability, a Third Place helps to augment individuals' intellectual horizons and afford a richer, broader experience of life for people (Jeffres et al., 2009). These social activities often take place in urban contexts via public plazas, community centres, shopping malls, local shops, religious places, and, today, the World Wide Web.

Wei et al. (2023) investigated the use of virtual reality (VR) to create Third Places that foster playful remote interactions, aiming to reduce generational divides. Their research employed participatory approaches to enhance the feeling of togetherness and spatial engagement within VR environments. This was achieved through the use of lifelike avatars, multisensory cues to simulate closeness, personalised settings to foster a sense of community, and the encouragement of emotional expressions that might be inhibited in real-life interactions. The study highlighted the importance of activity co-design. Participants collaborated to create shared virtual experiences like exploring remote destinations, engaging in hands-on activities based on mutual interests, and playing video games together.

Chou et al. (2022) created a VR game to facilitate intergenerational communication of traditional culture, identifying key factors that enhanced the user experience (UX) for older adults. Prior to the game, older participants experienced stress related to adopting new technologies, communicating with younger individuals. There was a prevalent fear of not being suitable to engage with younger generations, such as being unable to keep pace, causing inconvenience, and being ignored. The success

of the project demonstrated that increasing non-familial intergenerational interactions can alleviate the stress associated with feelings of incompetence among older adults. Also, VR environments designed with familiar content or themes, clear and explicit instructions, flexible asynchronous play options, and personalised learning curves can significantly improve the intergenerational UX.

In a pilot study of the same project, Wang et al., (2022a, 2022b) detailed the design of a tangible user interface (TUI) for more intuitive hand gestures to interact with virtual objects, distributing tasks between users—while older adult was controlling a virtual puppetry, youth was playing a piece of physical music instrument to assist the older player in maintaining a rhythm. As such, the VR game does not replace but complements real-life interpersonal interactions. Wei et al. (2023) also demonstrated a similar approach in asymmetrical task distribution, which involved assigning more complex tasks to younger participants and simpler tasks to older adults. With tailored controls and interfaces for each age group, it allows older adults to remain seated while in VR and gives younger participants more physically active roles.

Overall, VR-supported communication has shown promise in complementing real-life interpersonal interactions. However, further research is necessary to fully understand its impact on engagement quality. To achieve this, a comprehensive evaluation framework is needed.

2.3 Quality of Engagement: Evaluation Frameworks

As intergenerational engagement can have positive effects on personal and group developments, it can be evaluated by integrating and combining evaluation methods from both fields (Ames & Youatt, 1994).

Personal development falls in the domain of education and is the development of capacity and aspiration for self-actualisation (Rodrigues et al., 2015). Whereas group development can be understood using social psychology methods, which is the scientific study of how individuals' thoughts, feelings, and behaviours are influenced by social contexts (Allport, 1954). There can be two types of groups – formal ones who are 'structured to pursue a specific task' and informal ones that 'emerge naturally in response' (GovNL, n.d). Studies can look at how individuals respond to a specific task, while observing emergence in the self-organisational process that may deviate from the given structure. More specifically, behavioural descriptors of participants working as a team can include high or low dominance, sociability, and task orientation (Driskell et al., 2017). Overall, to study how individuals develop themselves within a team and how effectively the group is performing, one can:

- look at work engagement 'both at the individual and team levels', whether they are actively engaged, not engaged, or actively disengaged (Costa et al., 2014; Dawsey & Taylor, 2011).
- study how members organise themselves in the team by their task distribution and role distribution (Stempfle & Badke-Schaub, 2001).
- analyse individuals' social participation, for instance, Onojeghuo et al. (2019) analysed video recordings of children playing in a room and used a coding method to map social behaviours, so as to visualise and understand what may influence an individual's conversing, aggression, and other interactions with one another.
- evaluate whether the outcomes of the interaction are transformational (new shared-values emerged), non-transformational (predetermined values), or transactional (old values) (Nahon-Serfaty & Diaz, 2017).

An integrated evaluation framework (Fig. 3) considering the aforementioned points can help to assess the quality of intergenerational cooperation from levels of individual, group, and community.

3 Methodology

To investigate intergenerational cooperation in practice, a case study was developed in a high-density public housing estate of Hong Kong—Jat Min Chuen (JMC), with a focus on its public open spaces. The study utilised cooperative design methods—inviting residents and designers to collectively identify problems in the local plaza and develop design solutions to improve current conditions via a custom VR game. The study organised three distinct workshops, each with a unique intergenerational composition:

1. The initial workshop was non-intergenerational and served as an alpha test, which is typically conducted within the organisation, with university students (19–29 y/o).
2. The second workshop was moderately-intergenerational, a beta test conducted in the users' environment, extending its scope to youth (13–18 y/o) and middle-aged (41–60 y/o) individuals.
3. The final workshop was highly-intergenerational and the most diverse, bringing together all three generations, including older adults (60 + y/o).

This varied intergenerational approach aimed to identify any observable patterns in how different age groups interact with one another and with VR tools. The data collection and analysis deployed a combination of design documentation and behavioural mapping.

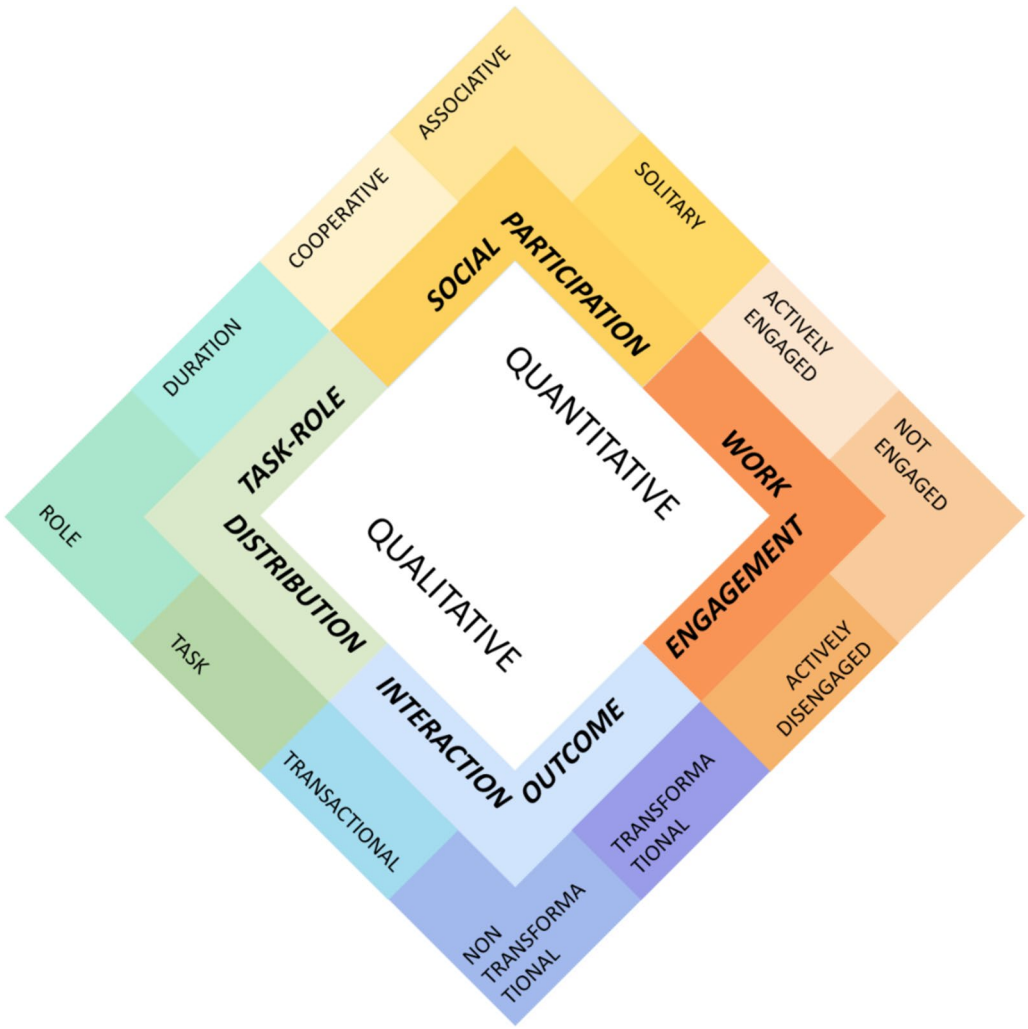

Fig. 3 An integrated evaluation framework of intergenerational programming

3.1 Participants Recruitment

The three workshops took place respectively on 21st November, 3rd and 10th December 2022 (Table 1). To balance participant engagement with the depth of discussion and feedback during the workshop, co-design experiments generally have a relatively small sample size, typically 15–25 participants (Malloy et al., 2023; Wang et al., 2022a, 2022b).

The first workshop (not intergenerational) recruited a total of 20 university students respectively from

Table 1 Workshop details

EVENT NO	DATE	PLACE	SYSTEM TEST	PARTICIPANT COMPOSITION	PARTICIPANTS TYPES & NUMBER		TOTAL	NO. OF TEAMS
1	21NOV 2022	University	Alpha	Not intergenerational	University Students	19	19	4
2	3 DEC 2022	JMC community centre	Beta	Moderately intergenerational	University Design Students Middle-aged volunteers Youth Residents	3 3 8	15	3
3	10 DEC 2022	JMC community centre	Beta	Highly intergenerational	University Design Students Middle-aged volunteers Youth Residents Older Adults Residents	4 3 7 7	24	4

architecture and sociology. Unfortunately, one student was absent on the day of the event due to COVID-19. The rest was evenly distributed into four teams.

The second workshop (moderately intergenerational) recruited a total of 15 participants through the local community centre but one was absent. Thus, the workshop had 3 design students, 3 middle aged adults, and 8 youth, evenly distributed into three teams.

The last workshop (highly intergenerational) recruited a total of 24 participants through the centre but three were absent. Thus, the workshop had 4 design students, 3 middle aged adults, 7 youth, and 7 older adults, evenly distributed into four teams.

3.2 Activity Design & VR Utilisation

The workshops were being planned using Ames and Youatt's (1994) intergenerational programming model (Fig. 2). First, goals were being set respectively in areas of entertainment, education, public service, health promotion, and personal development, including having fun together to establish rapport; facilitating an active learning experience; serving or being served by shared activities and motivating collaboration and communication; promoting social and environmental health and wellbeing; and developing capacity and aspiration for self-actualisation (Table 2).

Afterwards, activities were designed to match the objectives (Table 3). Giving consideration to practical design needs, the workshop flow was structured as a design thinking process (Glen et al., 2015). This included introductory activities (objective 1), empathise and understand each others' needs through persona exercise (objective 2), define problems through spatial analysis, ideate solutions of community activity based on common goals and distribute design tasks (objective 3), prototype to visualisation idea using VR environments and present the outcome (objective 4).

Participants would co-design the public space using a multiplayer sandbox game with a tailored VR environment (Fig. 4). VR headsets were used, but due to safety caution, participants were only immersed 5-min per time to review the design from user perspective. Otherwise, laptops with projectors and large TV monitors were used. All tasks related to working with VR environments are considered a VR task. After the first workshop, minor problems with the user interface had been identified and rectified, so the last two workshops utilised the β version of the game.

All three workshops were planned to be 3 h in duration. Participants worked in teams of 4–6, each team would have at least one representative from each stakeholder group, and shared 1–2 laptops, VR headsets, and

Table 2 The goals, objectives, and evaluation of workshop design

Goals		Objectives	Evaluation
Health promotion	Social and environmental health and wellbeing	1) To understand the importance of community building and placemaking	Work Engagement
Public service	For one to serve or be served by shared activities and motivate collaboration and communication	2) To learn to work as a community with people from different social groups	
Entertainment	Have fun together to establish rapport	3) (Older) adults: to set self-directional tasks and help participants feel relevant and/or useful. Children & youth: to set explorative tasks and help participants persist in these self-chosen tasks	Task-role Distribution
Educational	Facilitate an active learning experience		
Personal development	Develop capacity and aspiration for self-actualisation	4) To acquire social skills, design thinking, and digital literacy	Social Participation

Table 3 Workshop structure following a design thinking process

INTRODUCTION	EMPATHISE	DEFINE	IDEATION	PROTOTYPE	PRESENT
Talk	Personas exercise	Spatial Analysis	Identify Goals	VR Co-design	Show & Tell
objective 1	objective 2	objective 3		objective 4	
Introduction to co-creation, VR, and public spaces	Participants identify target user groups, needs, preferences, and daily routines	Participants immerse in 360 photos of the target site to analyse pros and cons of existing spatial design	Participants worked in teams to list out community activities that can support the chosen design goals	Participants worked in 3D virtual space on laptops, and used VR headsets to inspect the space at 5-min intervals	Each team presented their design and others contributed comments and feedback
20 min	20 min	20 min	30 min	60 min	30 min

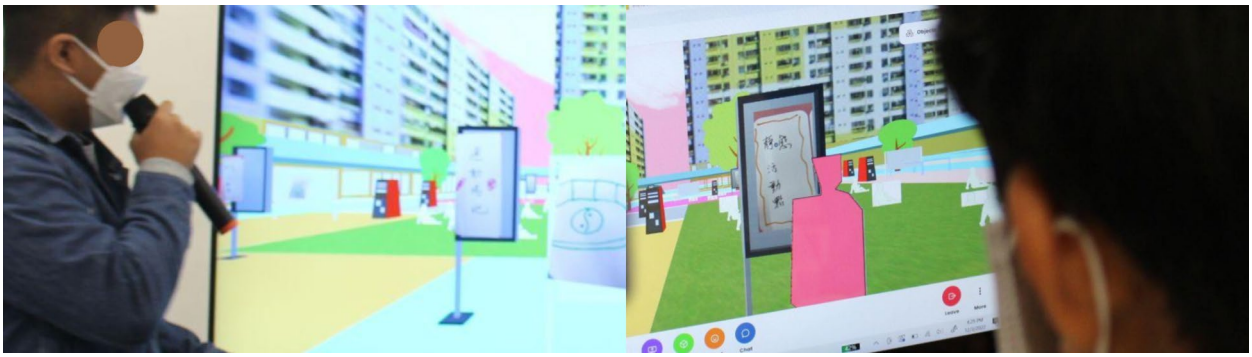

Fig. 4 Participants co-designed a public space in the custom VR game

other physical tools (i.e. pen and paper) to ensure participants with varying skills can all contribute.

3.3 Data collection & analysis: design documentation & behavioural mapping

Methods were designed to evaluate the quality and outcomes of intergenerational cooperation. Following the framework of Fig. 3, design documentation and behavioural mapping were used to collect and analyse data.

For interaction outcomes, design documentation was used to understand if new shared values and ideas were formed on community activities and public spaces. Design documentation includes documenting images of participants' handwritten notes, drawings, VR scenes, and transcripts of their presentations. Due to the limited time frame of the experimental setup, some teams were unable to complete their intended design in VR. Researchers would help participants to troubleshoot and round out according to their written notes, drawings, and presentation content.

To understand work engagement levels, task-role distribution, and social participation types, behavioural mapping was employed, which is a structured observation technique to identify 'locational or temporal patterns of behaviours' (Ng, 2016). This paper focused on team-based and individual-based temporal patterns. Throughout the prototyping session, photos were taken at a 5-min interval. Then, each participants' actions in the photos were being labelled with different colour coding (Fig. 5).

The labelling was categorised according to:

- work engagement levels adopted from Dawsey and Taylor's (2011) model, including:

  actively engaged—actively working on design tasks (green);

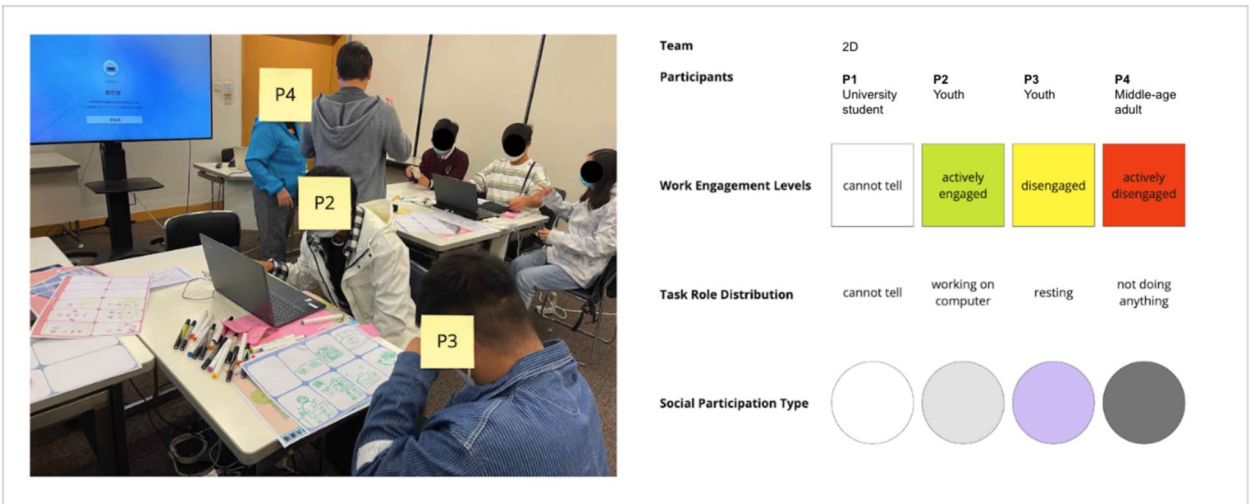

Fig. 5 Samples of work engagement, task-role distribution, and social participation analysis

not engaged—not working but still paying attention to what is happening in the team (yellow); and
actively disengaged—completely out of focus or working on other things (red).

- task-role distribution with a textual description of what each participant was doing in the photo, including

working in VR environments,
drawing,
finding references,
discussing,
observing,
resting,
not doing anything, and
cannot tell.

- social participation types adopted from Onojeghuo et al. (2019) are detailed in Table 4.

All labels were combined to generate a heatmap (Fig. 6), which were then used to derive a set of line graphs to study the optimal engagement time frame of each workshop. Afterwards, researchers and participants came together to discuss what was happening in each of the photos, review the analysis results, and consider anomaly in data, followed by a set of guiding questions:

- How was the overall team atmosphere and who was the most active in the team?
- Why were these participants not engaged at that time?
- What were participants working on throughout the process and how did they distribute the tasks within the team?

The discussion outcomes were used to compare with the behavioural mapping results.

4 Results

4.1 Design documentation: public space co-design outcomes

In this section, we will delve into the design documentation and analysis of the three distinct public spaces respectively co-designed by participants of workshop 1 (not intergenerational), 2 (moderately intergenerational) and 3 (highly intergenerational), each offering unique features and layouts according to their preferences and community needs (Fig. 7). All designs incorporated various zones as participants were invited to plan the spatial layout using specific colour coding before placing facilities in VR.

4.1.1 Design 1 by a non-intergenerational group

The first design was co-created by architecture and sociology students. Their design process was user-centric and began by imagining four users, each a member of a nuclear family:

> *"What we are trying to do is to create a more vibrant family life in this estate, have more different facilities and more space to suit the family, like the giant temple [pavilion] for the family to talk together."*

The key design feature was a giant pavilion serving as a focal point for conversations and gatherings, with various facilities around it that cater to family activities. A large movie projector screen was placed with bean bags for seating, providing a communal area for open theatre or sports playback *"so they can enjoy some movie or watch football match together."* Adjacent to this was a parent–child zone designed with a playground and rock-climbing facilities. Participants explained they wish to encourage inter-family exercise and leisure:

> *"[...] for other families to play together [...] you can*

Table 4 Social participation types adopted from Onojeghuo et al. (2019)

Cooperative	**The participant is interested in the team and activities, which are organised with assigned roles (increased self-identification with a group and a group identity may emerge)**
Active conversation	The participant is verbally communicating with another peer
Associative	The participant is interested in the group but not in coordinating activities, or when there is no organised activity (substantial amount of interaction involved, but activities are not in sync)
Onlooker	The participant watches but does not get involved with an activity, may offer comments or laugh with others but does not engage in actual activity
Unoccupied	The participant does not show focus or intent (e.g. staring blankly into space, not interested in activities), like twisting hair or fiddling with an object but is not concentrating on the activity
Solitary	The participant is seen alone at a distance from the team, centred on their own activity and pays little or no attention to the team
Cannot tell	cannot be seen clearly in the picture / distracted by the camera / unsure / group work finished

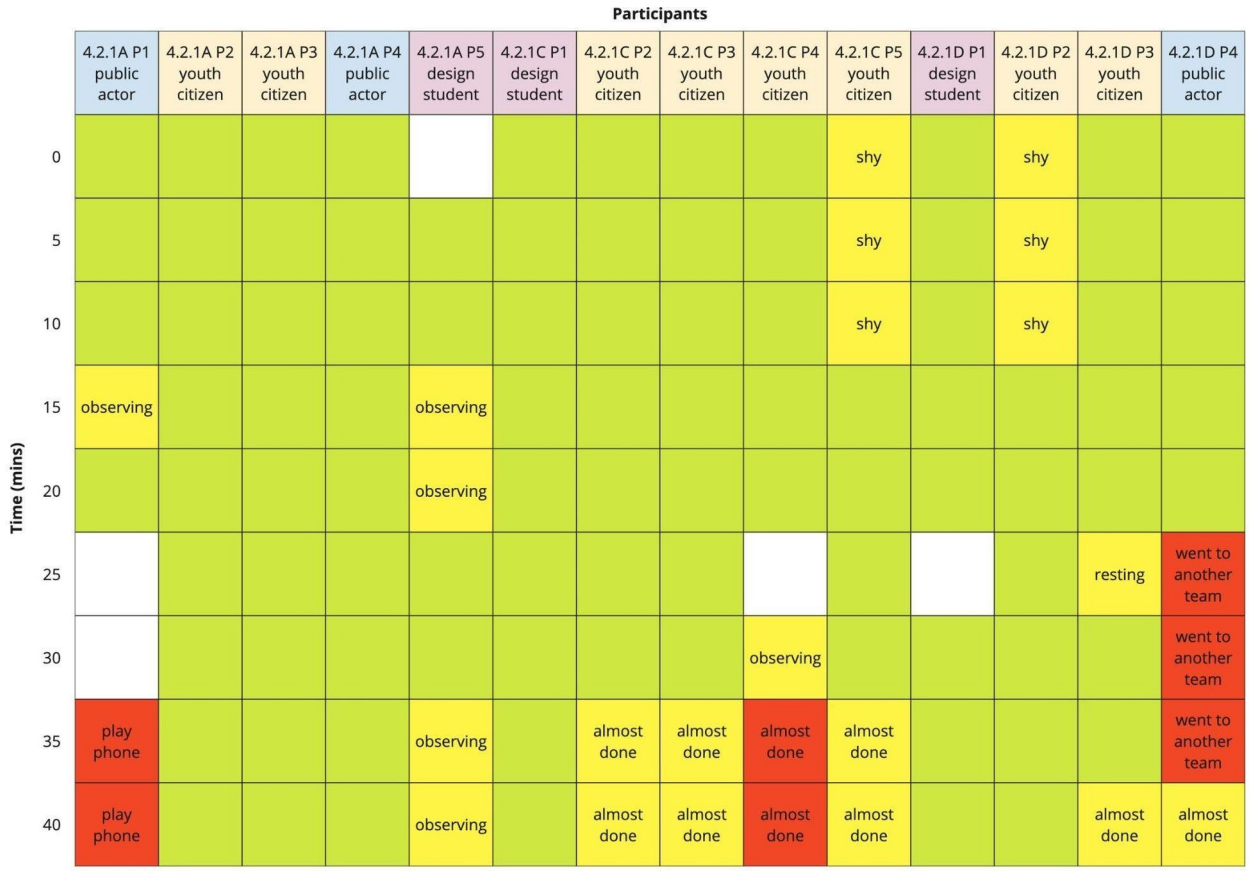

Fig. 6 A heatmap of work engagement levels of workshop 2 participants

do the child care at the same time when you are watching some movies and things like that."

The inclusion of an open, multifunctional area in the middle was intended for temporary events and stores, ensuring the space can adapt to different community activities. Educational opportunities were integrated through book-sharing and the presence of community shelves, promoting learning outside the classroom. Overall, university students co-created a multifunctional and family-oriented public space.

4.1.2 Design 2 by a moderately intergenerational group

The second design was co-designed by a team of youth residents, middle-aged volunteers, and design students. One of the key elements was the enhancement of interpersonal relationships, achieved through the idea of a "Jjimjilbang" – asian community shower rooms:

"When one person helps another one to shower, they can chat and relax together, and their relationship will enhance." "The one that has [back] rubbing."

These facilities were designed to encourage people in helping each other and promote a sense of camaraderie among community members. The shower rooms would charge affordably – *"around HKD 40 per use"*. Another important aspect was the mutual support element, embodied by the design of a community canteen where residents could feel united through shared meals and conversations. Each meal would charge HKD 40 as well:

"This is a community canteen. The tall handsome guy came from next door, which is the shower room." "You can feel it's very convenient and a sense of belonging." "There are people who sit around and hang out."

For pet owners, the design included a designated space with a very imaginative design – a cycling track surrounding a pet-friendly social space. This area allows people to engage in activities that were prohibited in public housing areas, such as scootering, skateboarding, and pet-keeping. Spatial efficiency is what inspired this integrated design:

"...a space for dogs, cats, and pigs, we surrounded

Fig. 7 From top to bottom, design 1, 2, and 3 respectively co-created by participants of workshop 1 (non-intergenerational), 2 (moderately intergenerational), and 3 (highly intergenerational)

it with a cycling track." "We designed this to save space."

Lastly, the design included a beach area, participants invited us to picture *"everyone bathing in the water"*. Additionally, there was also a basketball court *"with a 185 cm handsome guy"* and a dimsum tea house. Overall, the design focused on ensuring everyone feeling at home and comfortable in the public area, and reflects a comprehensive approach to community living.

4.1.3 Design 3 by a highly intergenerational group

The third design was co-created by a team of older adults and youth residents, middle-aged volunteers, and design students. One of the biggest areas integrated community exercises with a community stage. Designed for middle-aged Chinese women, known as Dama, the area was dedicated to plaza dancing and singing. A key consideration was noise pollution. To address this, the area was deliberately situated away from kindergartens to prevent disturbing children's classes. Such thoughtful placement aimed to balance older generations' need for lively activities with youth's need for a quiet environment conducive to learning:

"My grandchild told me to not go there, because it's noisy for them in class, there are two kindergartens there, so make some space [elsewhere], they can sing all they want, or sing facing the park."

Safety and comfort were also paramount. Instead of water features, which could pose risks for children, the space focused on practical facilities like markets and stalls near bus stops:

"I don't advise making a pond, should only make some facilities, like for eating, buy some food." "Yes, because they [the youth] originally proposed to make a pool, I said don't make it." "Afraid of accidents." "and the water may be dirty." "Yes, that is secondary, but near the bus stop, many children get off school."

Also, the design integrated spatial efficiency with inclusivity. For instance, chess-playing and children's libraries were integrated as a common space, so older adults can keep an eye on children to ensure safety, while each engages in respective age-appropriate activities, ensuring mutual help and accessibility to all ages. Further, ¼ of the total area was designed for older adults to engage in leisure activities, encouraging their participation and socialisation within the community:

"… Children, suitable for all, male, female, old and young, put them together, play chess, make space for some books, play something, and so on." "A community library.""Make some activity, make a space for older adults, sing some cantonese opera, there is [currently] a youth centre, but there is no older adult centre."

The environment quality was also a priority, emphasising the importance of maintenance, highlighting that even small improvements can enhance the overall experience:

"If you renovate it we support it, but if you don't, we don't have an opinion." "However, some improvement is better than not."

Finally, participants presented a unique approach to encourage social interaction through commercial use – instead of a community canteen, participants wished to have a community dim sum place and a 5-star dining spot. Overall, this public space design demonstrated a strong emphasis on inclusivity to all age groups, safety, and the efficient use of space.

4.2 Work Engagement

Highly intergenerational teams were most engaged with work, achieving the highest scores in terms of attention span. Workshops 1 and 3 particularly stood out for their high levels of work engagement. Workshop 1 was composed exclusively of university students, while Workshop 3, which was highly intergenerational, achieved the highest scores in work engagement span (see Fig. 8). Highly attentive individuals appeared to have a positive influence on the work engagement of other team members. In the top-performing teams, there was at least one individual who was fully engaged and working 100% of the time throughout the session.

University students exhibited both the highest and lowest levels of work engagement simultaneously. It was observed that groups 1B, 1C, and 3B demonstrated the highest levels of work engagement in terms of time span, with percentages of 100%, 88%, and 86%, respectively. The first two groups were composed entirely of university students. Notably, among all participants, none of the students fell within the category of individuals with the lowest level of work engagement. Of the highly engaged participants, 52% were design students, while 36% were youth. Instead, the majority of the least engaged individuals were middle-aged and older adults. However, it is important to recognize that not all students displayed equal levels of activity and enthusiasm. Their work engagement varied significantly among teams, as observed in workshop 1.

While the presence of older adults positively influences the overall work engagement level of the team, it is important to note that they may not consistently be the most engaged individuals. The scores for groups

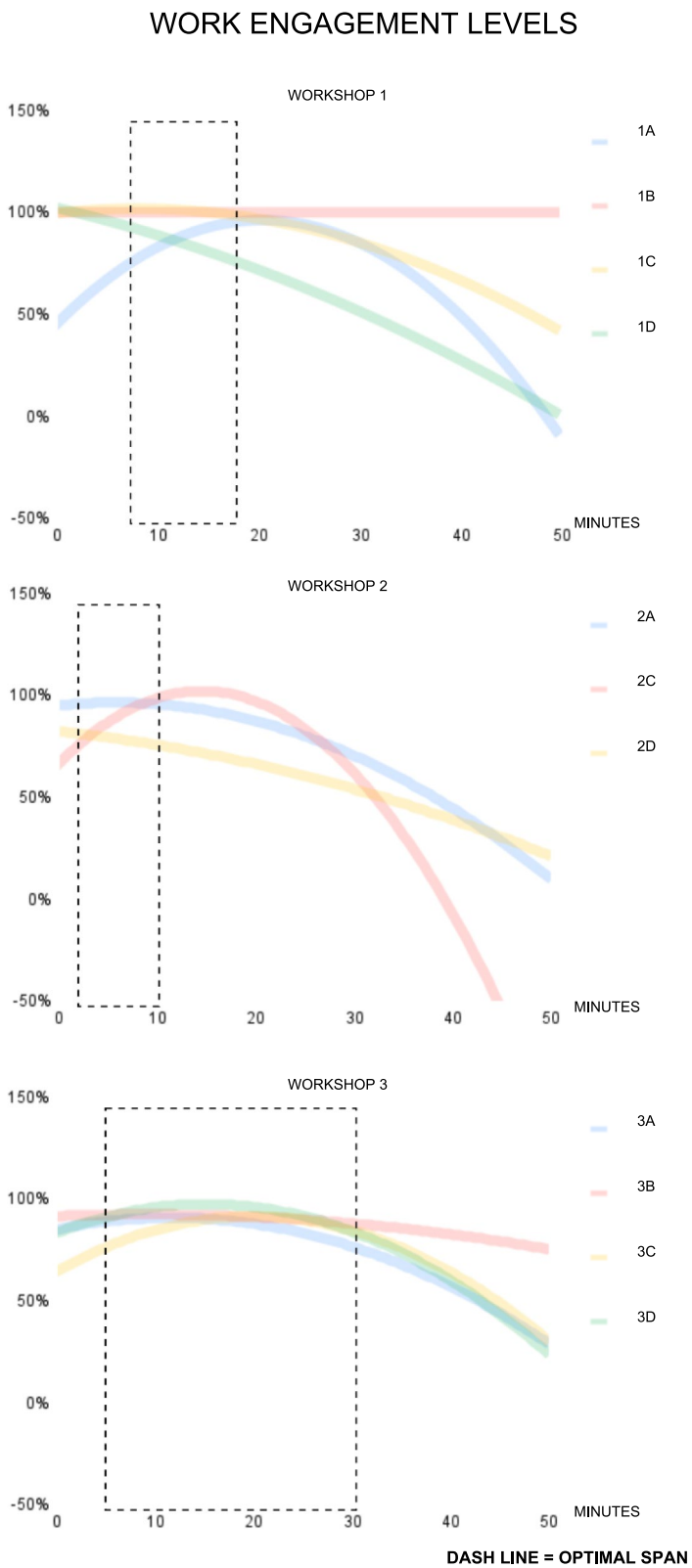

Fig. 8 Work engagement levels over time

comprising older adults consistently maintained an upper-middle level, indicating a positive influence with their presence and a stabilising effect on work engagement. Group 3B, for example, was highly intergenerational and most engaged in work throughout the session. Furthermore, two youths who exhibited the lowest level of work engagement (38%) during workshop 2 experienced a significant improvement when older adults were present, reaching 100%. However, it is worth noting that among the most engaged individuals in each team, none of them were older adults. On the other hand, when considering the least engaged individuals in each team, 27% were older adults, whereas only 9% were youth.

Enhancing the work engagement of middle-aged participants presents both challenges and significant potential. Workshop 2, which consisted of youth and middle-aged participants, had the lowest overall work engagement. The scores for groups 1D, 2C, 2D, and 3A were particularly low, primarily due to the underperformance of one or two individuals within these groups, most of whom were middle-aged participants. One individual in particular showed minimal engagement, with a 0% involvement in work. Meanwhile, another middle-aged participant who scored poorly (22%) in workshop 2 performed exceptionally well (100%) in workshop 3, which was highly intergenerational. This suggests that with the right workshop design, middle-aged individuals have the potential to be highly engaged.

These results shed light on the dynamics within intergenerational groups, highlighting the varying levels of work engagement among different age groups in the presence of others.

4.3 Task-role Distribution

Among all the tasks, participants were most involved in discussion activities across all age groups, each taking on a different role without specific instructions. Participants seemed eager to communicate with each other regardless of age. In their collaboration, each age group naturally exhibited behaviours of different roles within the team, respectively as leaders, facilitators, coordinators, and information providers (see Table 5).

Youth participants tended to be the most active in tasks, taking on leadership roles in 6 out of 7 intergenerational teams. They mostly dedicated themselves to leading discussions, drawing, and VR tasks (see Fig. 9). Some of them were initially shy, especially when unfamiliar with the tasks or team members, and required a more welcoming and fun atmosphere to become fully engaged. When they were not as active in discussions at the beginning of the session, it might give the illusion of a lack of motivation. However, upon reviewing the photo documentations, it became evident that these individuals were actually paying full attention. Once they developed an understanding and skills, they tended to implement the tasks until the end.

Design students were also quite active in tasks, taking on roles as facilitators in supporting others to complete their tasks. They were engaged in discussions, VR activities, and observation, and co-led group activities in two of the teams. However, they mostly positioned themselves as facilitators and were not as active in contributing ideas. Instead, they tended to facilitate the process (e.g. signalling what should be done next, help troubleshooting VR scenes, etc.). Initially, they gave the impression of reluctance and laughing at the tasks, but behavioural mapping showed that most of them were trying until the last minute, even when the VR game was not working well due to internet issues. This attitude of 'unseriousness' perhaps contributed to their ability to 'play' in VR and generate more creative ideas (e.g. suggesting interactive installations, metaverse community workshops, poolside barbeque carnivals, etc.).

Middle-aged volunteers tended to become disengaged or actively disengaged with tasks after 20–25 min, often taking on coordinator roles. One of them took on a leading role, while others mostly acted as coordinators. For instance, they discussed with older adults, assisted youth to improve proposals, or found reference images to guide others in drawing — something that other age groups had not performed. However, their behaviours were quite polarised, either contributing fully to tasks or not at all. The lowest performing individuals often presented themselves as a form of guardian rather than being part of the team. For instance, they made irrelevant jokes to

Table 5 task-role distribution according to social group

SOCIAL GROUP	WORK ENGAGEMENT	TASK	ROLE
Youth Citizen	60% participants engaged 100% of the time	Discussion, VR, drawing	Leader
University Students	50% participants engaged 100% of the time	Discussion, VR, observing	Facilitator / Leader
Middle-aged volunteers	50% participants engaged < 50% of the time	Discussion, observing, not doing anything	Coordinator / Guardian
Older Adult Residents	100% participants engaged > 50% of the time	Discussion, observing, drawing	Information Provider

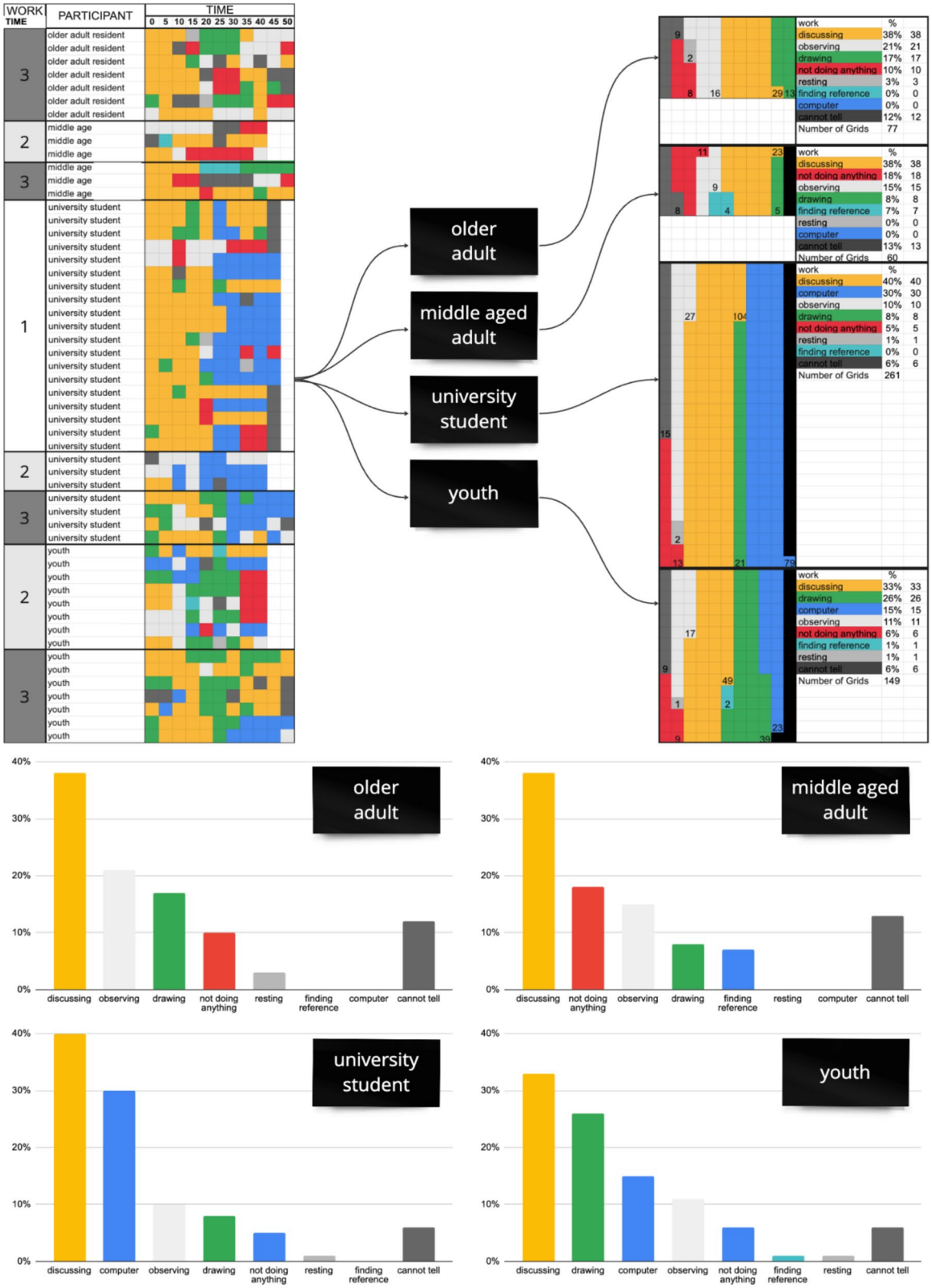

Fig. 9 Task-role distribution according to age group

lighten the atmosphere, left the team to check on another's progress, or observed other participants working. They began looking at their smartphone after 25 min and seemed to have been waiting for the event to end.

Older adult residents tended to be the least involved in tasks but were active in spirit, mostly taking on roles as information providers. Teams usually began with discussions, some older adults would observe and try to understand what was happening. Mid-way through, when there were more hands-on tasks, some of them had difficulties drawing due to physical mobility or eyesight challenges, but they would still make an effort. Towards the end, some older adults seemed tired and may have difficulty participating in more VR-oriented tasks, but generally paying attention to what others were doing until the end. The strength of older adults lies in their persistence, high spirits, practical thinking, and curiosity. They did not hesitate to contribute to discussions, were not shy to participate, and most of them stood up as presenters at the end of the session to share their co-design outcomes with others. If activities can be more tailored to their abilities, they could take on more active roles.

Most participants became more active in tasks and roles when older adults were present. Especially when there is a sense of need to help others, their leadership capacity shines. For instance, one youth participant who did not partake in drawing tasks during workshop 2 began engaging in drawing activities in the presence of older adults to help them visualise their ideas. In the process, older adults tended to suggest ideas that are more practical (e.g., having more cash machines and convenient shops to benefit the convenience of daily lives, etc.) and pragmatic (e.g., when someone mentioned placing a pharmacy, they immediately suggested placing some cabinets, etc.) and to avoid ideas that they perceive as dangerous or troublesome (e.g., many of them expressed that having sandboxes or pools would be 'dangerous' and 'troublesome' as children may drown or dirty themselves and have to be watched over). In such cases, youth tend to stay quiet, respect their opinions, and change the design accordingly.

In terms of completion time, workshop 2 (moderately intergenerational) finished fastest and workshop 3 (highly intergenerational) took the longest **(**Table 6**).** Participants of workshop 1 would first discuss and draw, then focus on VR-related tasks. In contrast, tasks were more evenly distributed throughout the session in workshop 3, going back and forth on discussing, drawing, and computing. In general, participants would spend 15–20 min discussing at the start of the session before moving on to other tasks. However, participants of workshop 2 spent half less time on discussion and started with VR-related tasks much sooner. Whereas in workshop 3, discussion happened more frequently and continued throughout the session. Occasionally, participants would self-initiate to search for references online around the same time as they started to draw, except for workshop 1, where no one seemed to have looked for any references. After 30–35 min, some participants began to actively disengage with tasks, with workshop 2 having the highest percentage of disengaged participants. By comparison, workshop 3 had the longest engagement span on average with the least amount of disengaged participants.

4.4 Social Participation

In terms of social participation, highly-intergenerational workshops resulted in highest status, followed by non-intergenerational, then moderately-intergenerational **(**Fig. 10**).** The most socially participatory teams were 1B (non-intergenerational) and 3B (highly intergenerational). The former team involved only university students. Even during a frustrating situation with a lagging VR game, all of the team members were laughing and persisting with the tasks. One of the members was quite

Table 6 task-role distribution according to each workshop

WORKSHOP		TIME SPAN (MINS.)			ACTIVELY DISENGAGED		MOST FREQUENT TASKS	
NO	INTERGENERATION	FINISH	DISCUSSION	VR	TIME (MINS.)	PARTICIPANTS	TASK	TIME
1	Not	50	15–20	20–25	After 30	37%	discussion	47%
							VR	27%
							not doing anything	7%
2	Moderately	45	5–10	30–35	After 35	50%	observing	25%
							computer	21%
							discussion	18%
3	Highly	55	15–20	20–25	After 45	29%	discussion	40%
							drawing	21%
							observing	12%

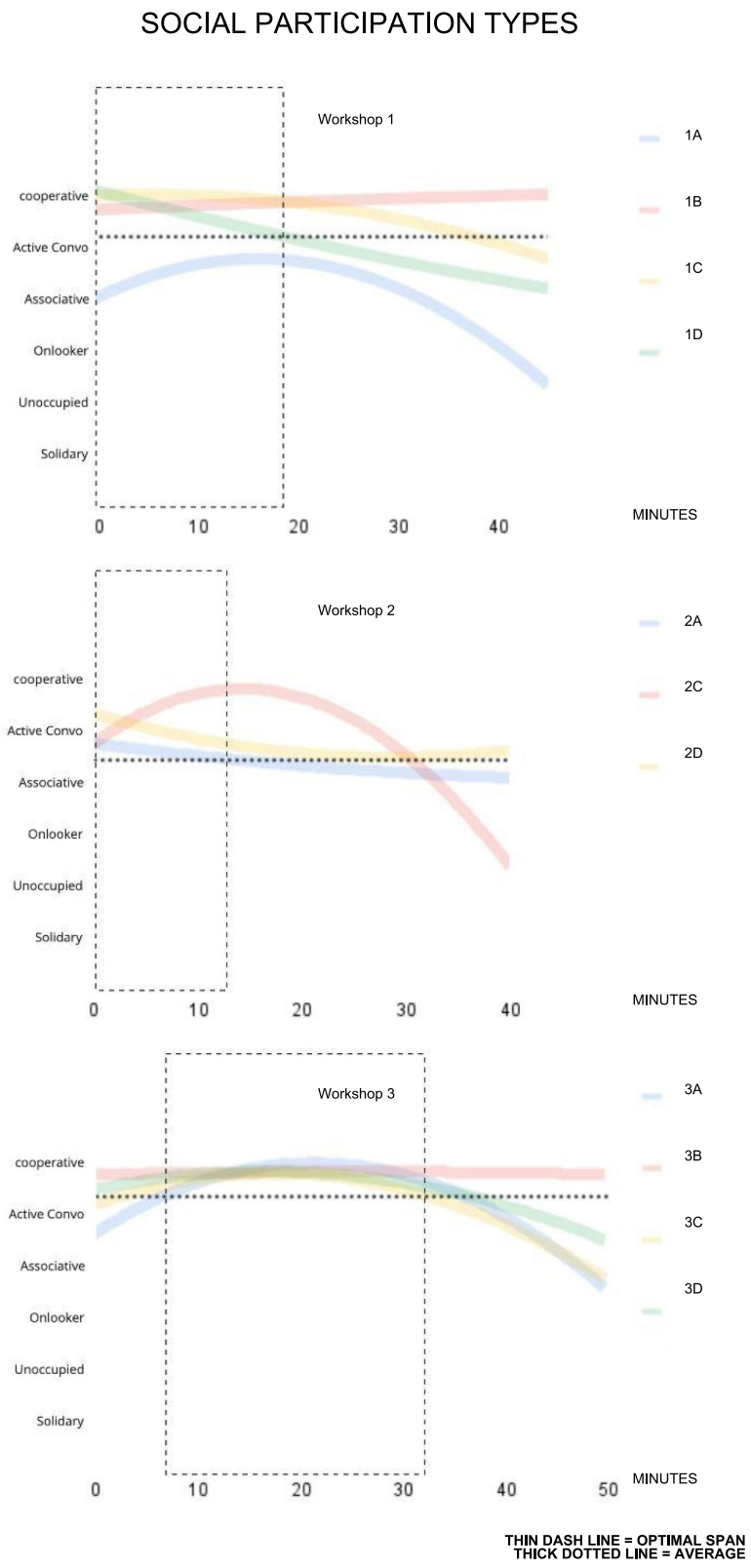

Fig. 10 Social participation over time

humorous and jolly; although he was the only one not working on VR tasks, he kept communicating with other members and paid attention to everyone's progress. The latter team had four out of five members who remained cooperative throughout the process, and although the older adult in the team did not cooperate on tasks, she remained in active conversations with others.

The presence of older adults had an effect of stabilising both the status and trends of social participation across all teams. Groups with older adults had similar trends, with an increased social participation status to the maximum in the first 15–20 min. Starting at 40 min, the status steadily declined, but all teams remained cooperative. It also lengthened the social participation span, averaging 20–25 min.

With only youth and middle-aged participants, the social participation span was the shortest (10–15 min). The least socially participatory teams were 1A (non-intergenerational) and 2A (moderately intergenerational), both without older adults. The former inclined and declined quickly, but the latter declined since the beginning and remained in a slow decline throughout the process. In team 2A, only one youth participant was highly cooperative; others were mainly associative. One of the middle-aged volunteers was unoccupied or remained solitary for more than half the session. Although the design student in 2A helped with more complex VR tasks, they were mainly an onlooker during other times.

With only youth, the status across teams was the least consistent. By observing the behaviours of team 1A, all of whom were university students, two out of five formed a sub-group, who mainly discussed amongst themselves or remained onlookers. Whereas in the other teams, there were always one or two participants who tried to involve everyone. The largest fluctuating team was 2C, with only design students and youth participants. The social participation status rose higher than all other teams at first, then quickly fell below everyone else. Some of the youth were friends and got acquainted with other team members in the first 15 min and stayed cooperative. After which, two of the youth became onlookers or stayed solitary. As the session reached the end, all youth became unoccupied, only the design student remained cooperatively on the allocated tasks.

Overall, social participation was linked to complexity of tasks, capacity to multitask, and role distribution. "Cooperative" status tended to occur at the beginning of the workshop in about 10 min, when participants became familiar with each other and began discussion. In the following 10–15 min, participants divided tasks amongst themselves, and group cooperation reached its highest level. "Active conversation" was often correlated with participants who were actively engaged and eager to present their ideas, but were reluctant or found it complicated to write or draw them. They were often found among older adult participants. "Associative" mainly happens when participants were not clear how they can help with the tasks or what their roles were within the team; this can also lead to "onlooking", but mostly happen to middle-aged adults or university students when they were alone with youth. The decline of social participation was often correlated with VR tasks, which made it difficult to maintain stable communication, even when they were not immersed in headsets but simply using the computer. When participants began to feel difficulty or exhaustion, they would become "Unoccupied" or leave their group to become "Solitary".

5 Discussion: Enhancing Intergenerational Cooperation and Co-creation in Public Space Design

The results have shown that when the overall social participation increased, work engagement also tended to increase. However, it is worth noting that some individuals might be more inclined to socialise rather than actively contributing to work. This highlights the importance of striking a balance between social interaction and task completion.

When only two generations (i.e., youth and middle-aged individuals) were present, work engagement, task-role execution, and social participation all tended to be lowest. When only one generation was present, the performance was above average; however, sub-grouping tended to occur. The presence of all three generations led to higher overall engagement and group cohesion, suggesting how intergenerational cooperation had a positive impact in promoting altruistic actions, motivating individuals to take care of others. However, it also presents many challenges in tailoring co-design tasks that are suitable for all age groups, especially with the use of VR tools, which will be further discussed in this section.

5.1 How different age groups interact with VR tools

The results suggested that the use of VR tools impacts participants' behaviour differently across age groups.

Youth individuals exhibited higher engagement in leading VR activities, showcasing comfort with the technology. However, there were communication challenges when they were focused on VR tasks, which may lead to decreased social participation. This emphasised the importance of maintaining intervals of physical interaction time in between.

Adult participants in middle age showed varied levels of engagement with VR tasks, in most scenarios, did not work directly with VR tools. Their low performance may be related to unfamiliarity with VR technologies, causing

them to lose motivation. This suggested the need for means to sustain their interest through more hands-on practice.

Older adults generally expressed willingness to try VR tools with proactive mindsets. There were challenges for them to engage in hands-on tasks, potentially hindering full participation. However, experiencing spatial designs in VR stimulated them to contribute insights and offer practical suggestions. Some individuals with mobility challenges could not reach the site physically but were excited to visit it in VR, ensuring their perspectives are considered in the process.

In best performing teams, older adults were often present, and youth became more motivated in overcoming VR challenges, while middle-aged participants tended to be more proactive in assisting the co-design process. Otherwise, they might be more susceptible to distractions from external factors or leave the VR task with design students to complete after initial trials.

The worst-performing teams consistently have higher proportions of middle-aged adults. One of them shared reasons on their disengagement with VR activities, and responded they were content with the youth's preferences "in the game" and therefore did not feel the need to intervene. This highlighted the necessity in helping middle-age participants feel more relatable to VR activities.

Overall, in terms of work engagement, VR engagement fluctuated between teams without the presence of older adults. For task-role distribution, VR tasks were mainly conducted by youth and university students, who often take on leadership roles at the same time. Social participation status was most affected by VR activities and seemed to have a negative correlation.

In sum, VR serves as a valuable tool for spatial communication in a highly intergenerational setting. However, careful design of VR activities is crucial to ensure full engagement of all participants.

5.2 The role of VR tools in supporting design participation

From the results of work engagement, task-role distribution, and social participation, this section suggests best practices of VR activity design to support intergenerational co-creation (Fig. 11).

Complementing physical interactions with cyclical practice. VR provides opportunities for participants to learn to improve their design decisions through iterative trial-and-errors, which is challenging to conduct in physical reality. However, the result of work engagement levels suggested that a mix of age groups may result in various duration of optimal engagement span. Organisers had to focus not only on design outputs, but also develop expertise in observing and sustaining group energy levels.

Shared activities with skill-appropriate interactions. Simulated 3D environments can create shared virtual activities that enhance intergenerational experiences. However, the result of task-role distribution showed that shared activities should be complemented by skill-appropriate interaction designs, with more creative VR tasks assigned to youth participants, more practical tasks assigned to older adults, coordination tasks assigned to middle-aged participants, and complex tasks assigned to university students, allowing for a more inclusive and tailored experience.

Bridging Generational Gaps through a guided process. A fun but challenging experience in VR can increase the need for collective problem-solving, enhancing a sense of co-presence and establishing rapport. However, the result of social participation suggested how VR could impede communication when participants were overly-focused in virtual environments. This highlighted significance in setting up a well-guided process, prescribing time for interaction and discussion before and between hands-on tasks, with interim communication periods oscillating between group and individual tasks.

All in all, the use of VR in co-design is still in exploratory phases. Beyond the initial problem of overcoming skills gaps between professional and laypeople, it has become increasingly apparent in the process of this study that much more effort has to be put into digging out the latent problems embedded in team dynamics and cooperation challenges. On the other hand, potential values that emerge from the interaction outcomes should be considered.

5.3 Interaction Outcomes: transformational vs transactional

Based on the evaluation framework (Fig. 3), the interaction outcomes can be understood as transformational (new shared-values emerged), non-transformational (predetermined values), or transactional (old values) by comparing them with each other (Table 7) and with existing design (Fig. 12).

Despite their unique characteris, all three designs shared common features that contribute to creating environment comfort. Each design incorporates shelters and shades against the strong sun. Further, all three designs seemed to put passive activities (e.g. landscaping, dining, sun-bathing, and reading) on the south-east side next to the existing wet market, which are often crowded with older adults.

While the designs share common features, they also exhibited notable differences that set them apart in terms of architectural style, facility distribution, and layout organisation. In the first and third design, traditional Chinese elements, particularly in the form of pavilions or

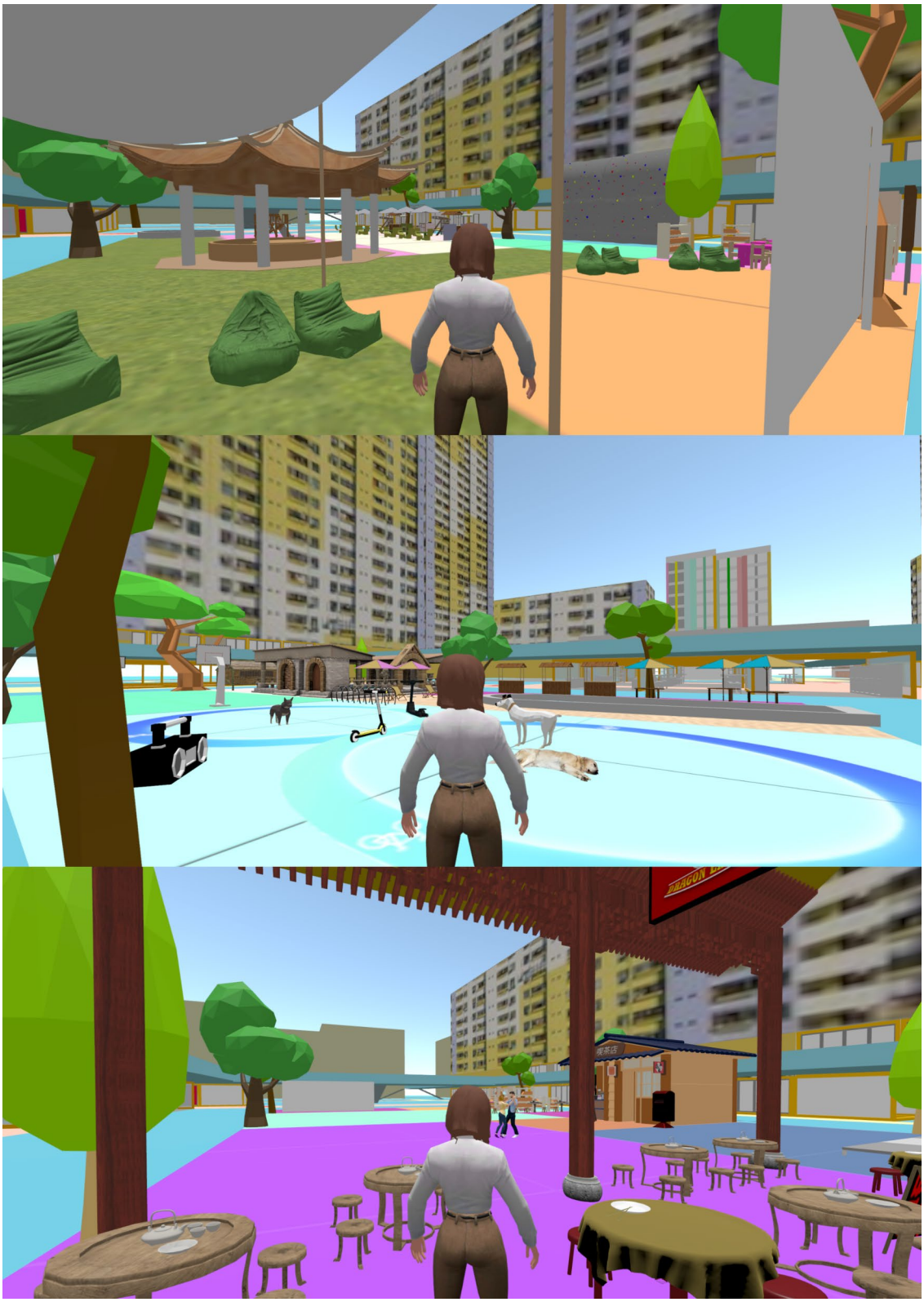

Fig. 11 Participants' co-created public space design being experienced from end-user perspectives using VR-based technologies, which can potentially transform the way architects design, communicate, and produce build environments with more empathetic, collaborative, and inclusive practices

Table 7 Comparing the three co-design outputs and participants' performance in Table 6

Workshop		1	2	3
Participants		Not intergenerational	Moderately intergenerational	Highly intergenerational
Engagement		Moderate	Low	High
Attention Span		30 min	35 min	45 min
Task Span		50 min	45 min	55 min
Features		Outdoor seating with tables and chairs under umbrellas	Outdoor seating with tables and chairs under umbrellas	Seatings in small buildings or structures
		Small water feature or pool	Small water feature or pool	—
		presence of traditional architectural elements	—	presence of traditional architectural elements
Zones	**Overall**	integrate zones more fluidly	Central circular area, for activities like skating or interactive play	integrate zones more fluidly
	Green zone (exercise)	rock-climbing	basketball court	plaza dance
	Purple zone (community support)	children library next to movie plaza	a pool with stalls, deck chairs and umbrellas, suggesting a leisure area	Open space with a community centre or chinese restaurants
	Orange zone (events)	Movie plaza and sports playback	—	Community stage
	Peach zone (commercial)	Food stalls and markets	Community bathhouse	—
	Pink zone (playground)	Features a swing and a slide	—	—
	Navy zone (study/ work)	—	—	Community library
	Brown zone (seating)	—	—	Chess tables next with tea
	Blue zone (skills building)	—	Cycling, scootering, skateboarding with pets and music	—
Differences		Activity Focus	Design 1: focuses on play and relaxation Design 2: water activities and interactive play Design 3: social interaction and potential commercial use	
		Architectural Style	Design 1: focus on greenery Design 2: summer party atmosphere Design 3: traditional chinese elements	
		Layout	Design 1: mixing seating, play, and relaxation areas Design 2: more segmented with clear zones and organised separation of different activities Design 3: mixing activities of different age groups	

larger structures, were integrated to add a sense of cultural significance. The second design created an atmosphere of summer parties. Additionally, first and third designs strategically placed seating throughout the public space to offer comfort and relaxation opportunities. Whereas the second design seemed to be lacking sitting amenities. Finally, the second design featured clear zones for different activities, while the first and third designs integrated zones more fluidly within the space.

Overall, compared to existing design, it can be observed that all of the co-creation outputs showed transformation outcomes as new shared-values have emerged, including community activities, architectural style, and layout organisation. Comparing them with each other, it appears design 2, which was created by a moderately-intergenerational team, was the most transformational for its uniqueness in all aspects. However, in terms of practicality and implementability, such transformational design can sometimes fall short. This also highlights a crucial question in community co-creation for local public spaces: what should be the benchmark, transformational or transactional?

5.4 Limitations & Next Steps

Lastly, all such insights should be considered alongside existing research limitations.

First, the dynamic and intangible nature of cooperation and its related variables makes measurement challenging. While insights were gained through work engagement, task-role distribution, and social participation, consistency between variables remained unassessed, affecting the capacity to prove any causal relationships between interventions and outcome quality. For instance, although results showed that middle-aged participants scored lower, there could be dependent variables like activity designs not being age-inclusive enough.

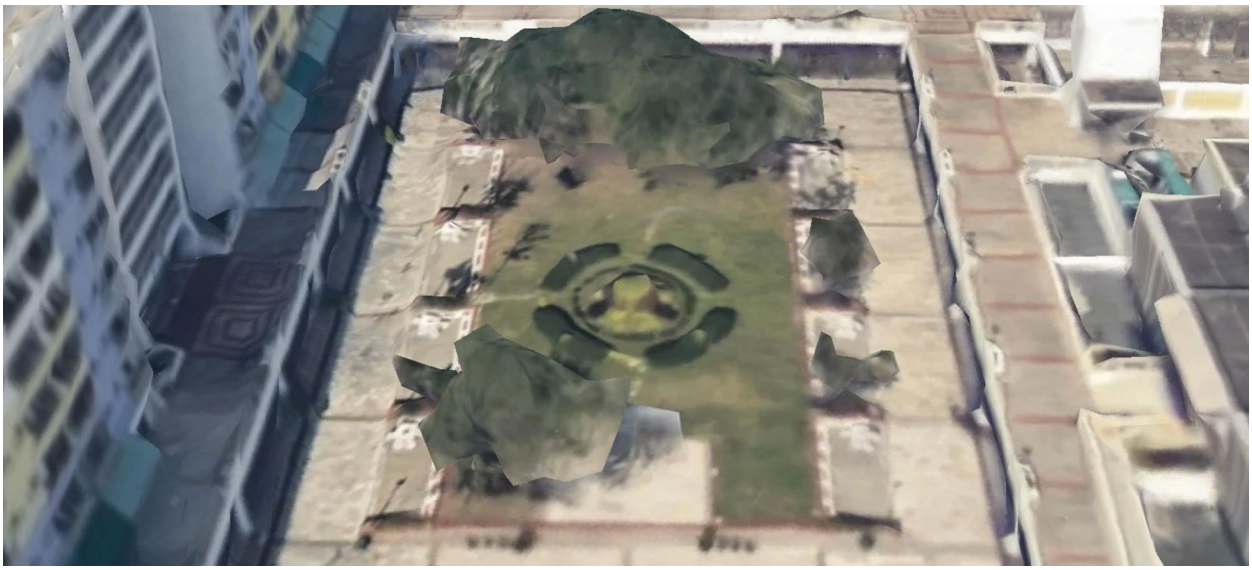

Fig. 12 Existing design remains largely the same since its construction in the 1980s, with green landscaping and seating. However, it is often under-utilised as the climate can get quite hot and humid without the design of shading. Also, walking on grass is prohibited. Image credit: Google Earth

Second, the COVID-19 pandemic limited emotion assessment due to mask-wearing, focusing analysis on bodily interactions. Also, unforeseen circumstances, such as a participant falling ill and absent could impact results, highlighting existing challenges of real-world co-creation workshops.

Third, in data collection, presence of cameras might influence participant behaviour, and static photos have limitations in capturing transitional moments and movements. However, simplicity and ease of application in our method made it suitable for cases involving extensive hours of interaction data.

Finally, convenient sampling might have biassed the study by recruiting participants already interested in VR technologies. The lack of participants in the 30–40 age range was also a concern. The limited number of participants highlighted the need for a qualitative approach.

Despite the descriptive nature of this study, its methods and outcomes could inspire application in similar contexts. The study will consider several next steps. First, expand and diversify the sample size. Second, redesigning the activities by studying the needs and preferences of middle-aged participants. Third, expand on the post-workshop collective reflection exercise to look at the problems in-depth. These next steps aim to further contribute to the development of effective and inclusive practices in urban co-design.

6 Conclusion

This study was conducted in the context of a high-density fast-ageing society, and in public housing with a well-connected network of local community centres. The opportunities were a readily participatory crowd with relatively high education levels, and older adults who had been active in local events and services. However, the challenge was to enhance public participation in an increasingly digitised and technical urban development process, where Virtual Reality (VR) was tested as a design communication and collaboration tool.

Focusing on the roles and impacts of VR, the study demonstrated varied outcomes across age groups. Youth participants exhibited comfort and leadership in VR tasks, while middle-aged participants showed mixed engagement levels. Older adults, though not as active in VR, demonstrated a proactive attitude. This indicates the potential of VR to be a medium for intergenerational engagement when activities are appropriately tailored.

Examining the enhancement of design participation through intergenerational collaboration, the study observed that mixed-age teams had higher overall engagement, with older adults positively influencing team dynamics. This collaborative approach fosters both transformational and transactional exchange of ideas, with each age group contributing unique strengths—youth offering creativity and technical skills, middle-aged

participants providing coordination, and older adults emphasising community needs and practicality.

In conclusion, our study demonstrated the complexities involved in enhancing community engagement during co-design processes, juggling parameters from quality of design output to unleashing full potential of all participants, synthesising disciplinary knowledge from urban development, game design, group dynamics, social psychology, interaction design, active learning, and intergenerational programming. It hints at a future where tools falling between these established fields may gather as a new form of expertise that can better serve tomorrow's society with inclusive practices—co-creators.

Authors' contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Data availability

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Declarations

Ethics approval and consent to participate

The studies involving human participants were reviewed and approved by Survey and Behavioural Research Ethics (SBRE). The participants provided their written informed consent to participate in this study.

Competing interests

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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