Integrating agent-based modeling, serious gaming, and co-design for planning transport infrastructure and public spaces

Yang, Liu; Zhang, Lufeng; Philippopoulos-Mihalopoulos, Andreas; Chappin, Emile J.L.; van Dam, Koen H.

DOI
10.1057/s41289-020-00117-7

Publication date
2020

Document Version
Final published version

Published in
Urban Design International

URBAN DESIGN International
https://doi.org/10.1057/s41289-020-00117-7

ORIGINAL ARTICLE

Integrating agent-based modeling, serious gaming, and co-design for planning transport infrastructure and public spaces

Liu Yang[1,5] · Lufeng Zhang[1] · Andreas Philippopoulos-Mihalopoulos[2] · Emile J. L. Chappin[3] · Koen H. van Dam[4]

Abstract

Car-oriented transport infrastructure developments have had detrimental impacts on the public realm in terms of poor walkability and fractured leftover urban spaces. To build integrated transport infrastructure and public space systems with considering non-motorized travelers' behavior, we present an integrated methodology incorporating an agent-based simulation model, serious games, and co-design which provides opportunities to involve citizens into the urban design process. In this paper, we show this process for a case study in London Hackney Wick. Qualitative data collected from collaborative experiments, cognitive and human needs mapping, interviews and conversations offer insights into people's engagement with their environment and the public expectations. In parallel, an Agent-Based Model (ABM) informed by the gathered data is used to visualize local activities for the residents and to predict travel demand and spaces occupancy patterns of various designs. The prediction results indicate that a holistic design strategy is needed for planning attractive and pedestrian-friendly transport-public space systems. Lessons learned also lead to a proposal to improve the model with more realistic human behavior and activity schedules. The coupling of ABM–Game–Design is a valuable tool for engaging the audience and providing both qualitative and quantitative supports to decision-making.

Keywords Co-design · Agent-based modeling · Transport infrastructure planning · Public space · Serious games

✉ Liu Yang
yangliu113@mails.ucas.edu.cn

✉ Koen H. van Dam
k.van-dam@imperial.ac.uk

Lufeng Zhang
zhanglufeng@ucas.ac.cn

Andreas Philippopoulos-Mihalopoulos
andreaspm@westminster.ac.uk

Emile J. L. Chappin
E.J.L.Chappin@tudelft.nl

1 Center of Architecture Research and Design, University of Chinese Academy of Sciences, Beijing 100190, China

2 The Westminster Law & Theory Lab, University of Westminster, London W1W 7UW, UK

3 Energy and Industry Group, Department of Technology Policy and Management, Delft University of Technology, Jaffalaan 5, 2628 BX Delft, The Netherlands

4 Centre for Process Systems Engineering, Department of Chemical Engineering, Imperial College London, London SW7 2AZ, UK

5 Centre for Transport Studies, Imperial College London, London, UK

Published online: 06 March 2020

I hear and I forget. I see and I remember. I do and I understand – Chinese proverb

Introduction

Urban design issues

It has been shown that a lack of connectivity and walkability in transport systems, poor aesthetic design and low accessibility of public space systems, along with low density and mixed-use of land use systems account for a decrease in physical activity (De Nazelle et al. 2011; Ewing and Cervero 2010). In urban areas, public spaces play a significant role in supporting pedestrian and cyclist movements, as well as in stimulating social interactions. Having prioritized the efficiency of motorized travel for decades with neglecting the social impacts of transport infrastructure development (Buchanan 1988), urban researchers and practitioners become aware of the necessity for taking into account public realm in transport network planning. Due to the negative impacts of transportation development on urban spaces and healthy behavior, it is generally accepted that an integrated design of Transport Infrastructure and Public Space (TIPS) systems is needed (Cervero 2009; Ravazzoli and Torricelli 2017; Waldheim 2012). In this regard, considerable research have been conducted in terms of Integrated Land Use Transportation planning (Bertolini et al. 2005; Maoh and Kanaroglou 2009), Shared Space practices (Ruiz-Apilánez et al. 2017), and developing design methods for drafting and evaluating transport-spaces plan scenarios (Moughtin 2003; Van Dam et al. 2014). In order to build a holistic and sustainable TIPS environment, scholars have advocated engaging public participation and multi-disciplinary cooperation into the urban design process which includes site analysis, design procedure, plan assessment stage, and decision-making (Nieuwenhuijsen et al. 2017; Yigitcanlar and Kamruzzaman 2014; Zhang et al. 2018).

Co-design

Participatory design (or cooperative design) has its roots in Scandinavia in the 1970s. In recent decades, user participation has been encouraged in urban design and planning discourse to gain participants' mutual understanding of design processes or to motivate the acceptance of a design initiative (Vainio 2016). Public participation, which is not simply a "tokenism," involves the community to define problem areas, to build up a strong sense of commitment, to generate a reliable source of information for spatial planning and to identify the needs of vulnerable groups in democratic decision-making (Lee 2008; Sanoff 1990; UN-Habitat 2016). On this basis, Ezio Manzini further extended the notion of participatory design to co-design. The co-design approach exceeds public consultation by creating equal cooperation between citizens, influenced by, or intending to solve a problem. This approach expresses a fundamental change in the traditional designer–user relationship (Chisholm 2017). Manzini highlighted that the roles of design experts in co-design processes are using their knowledge to conceive focused design scenarios, to stimulate the non-experts' ability of design, and to transform their ideas into realistic drawings, leading to new design knowledge (e.g., design tools) (Al-Kodmany 1999; Manzini 2015).

One prominent way of engaging the public is visualization because it is the common language through which both experts and non-technical participants can communicate. Visual image, captured from the city appearance along with city models and media, plays a critical role in educating citizens on perceiving the real world and stimulating discussions regarding expected changes in their communities (Hanzl 2007; Lynch 1960). Such a visualized public engagement method can be supported by various technologies, such as Geographic Information System (GIS), prototyping, 3D models, computer simulations, and photo manipulation during different stages of the planning and design process (Al-Kodmany 1999; Hanzl 2007).

Simulation models for co-design

In general, simulation models are built for prediction, explanation, theoretical exposition, description, or illustration purposes (Edmonds 2017). In planning and urban design domains, they can support the analysis and evaluation of alternative spatial configurations by representing physical infrastructures along with their users and predicting human activities and trips under a given transport network—land use layout. To support the co-design, Agent-Based Model (ABM) simulations are the most prominent ones (Edwards and Smith 2011; Vainio 2016; Van Berkel and Verburg 2012). Though simulation models that incorporate human behavior are capable of understanding how people respond to their environment, these models need to be carefully set up to produce useful and reliable results. Validation is often cited as a challenge for ABMs—one solution is to compare model outcomes against empirical data (Gilbert 2007; Gilbert and Troitzsch 2005; Macal 2016). Validation of social-science-based models through observation or survey has attracted much attention recently (Hahn 2013). Participant observation can provide precise information about individuals' interactions, their perceptions of the world, and the motivations underlying human behavior (Robinson et al. 2007). One can also start building simulation models from survey data. For example, Bonabeau (2002) gives flow management as an area where surveys or observed movement patterns can provide input for the origin and destination pairs in agent-based modeling. Dia (2002) uses questionnaires completed by drivers to calibrate parameters that represent agent preferences and Liao et al. (2012) ask visitors to a building some questions to set parameters for agents that simulate occupancy patterns.

Serious gaming as a tool for gathering qualitative data

Another challenge of agent-based modeling is a lack of qualitative data in generating realistic agent behavioral rules, in line with a lack of accurate description of the environment that intimately affects and affected by human behavior. Games give a way to address such a challenge. As a useful tool to get a strong involvement of users (Jahangirian et al. 2010), games can motivate people because they are fun. They can be used as a tool for communication (Duke 1980; Kelly et al. 2007) or instruction (Meadows 1999). Gosen and Washbush (2004) used gaming for the exploration of policy effects. Serious games, differentiating from the games purely for entertainment, can contribute to the achievement of a pre-defined purpose-formulated by the designer. Serious gaming knows a long history of military applications (Smith 2010), but also business and management science, economics, intercultural communication, and healthcare (Escobar-Castillejos et al. 2016; Mayer 2009; Raybourn 2007). Moreover, it offers an understanding of possible behavior in the real world, for instance to observe behavior and extract behavioral rules (Van Os 2012). In recent decades, the worlds of entertainment games and serious games are more and more mixing/overlapping, for instance, by means of cross-platform game engines, such as Unity3D framework (Unity).

Gap and aims

However, in an attempt to achieve an integrated TIPS design, more work is needed to clarify the way of engaging the public into the specific processes of project analysis, design, evaluation, and decision-making. Despite the growing concern of using simulation models to support the stages of analysis and appraisal, it is still necessary to use qualitative empirical data to inform, refine, or even validate these models to build a good representation of the real world. To bridge this gap, the paper aims to

- provide a co-design methodology for building integrated TIPS systems;
- create a computer model to engage the public and to support project analysis and scenarios appraisal;
- collect comments and expectations from the residents on problems they would like to address and gain insights in user behavior that could be included in the simulation model itself to make it more realistic.

To this end, the novelty of this paper lies in integrating agent-based modeling and serious gaming into the co-design process for engaging with citizens, informing the model development, and creating "collective knowledge" for urban design. A preliminary ABM of a research site presented to the participants allows them to construct a clearer image of the surroundings and incites discussions among them. This paper is an extended version of work presented at the Social Simulation Conference 2018 (Yang et al. 2018). We expand the earlier work by eliciting an integrated design methodology and feeding the qualitative data back into co-design processes.

The remainder of this article is organized as follows. In the following section, we present the proposed integrated methodology along with a conceptual "banana" model, followed by a description of the three-step serious game and

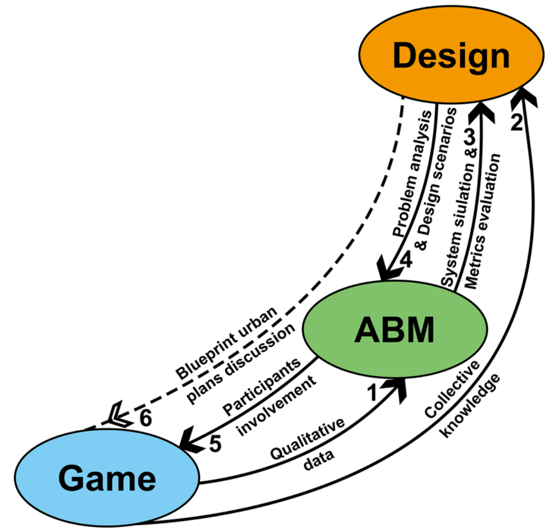

Fig. 1 A conceptual model of integrating ABM, games, and design

the ABM designed for this research. In "Case study: London Hackney Wick" section, the coupled method is applied to a study area in London Hackney Wick. Afterwards, "Urban design – ABM evaluation – Redesign" section shows an integrated TIPS scenario inspired by the empirical data derived from the engagement activities. Both the new plan and the baseline scenario are then tested in the ABM, leading to a redesign process for eliciting an ideal plan in terms of active travel demands and the use of public spaces. "Discussion" section demonstrates how the games ("games" refer to "serious games" in the following text) could be used to improve the model further and reflects on the lessons learned.

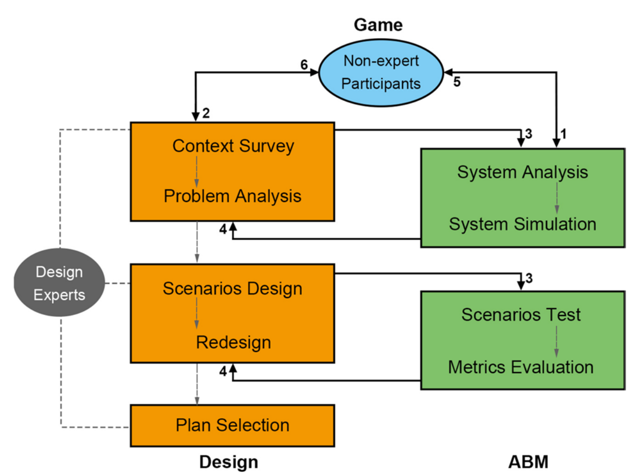

Fig. 2 An integrated design methodology for TIPS systems planning (the numbering and meaning of the black flows correspond to Fig. 1, dash lines in design blocks indicate the urban design process, dash lines in ABM blocks represent the modeling process). Adapted from Yang et al. (2019)

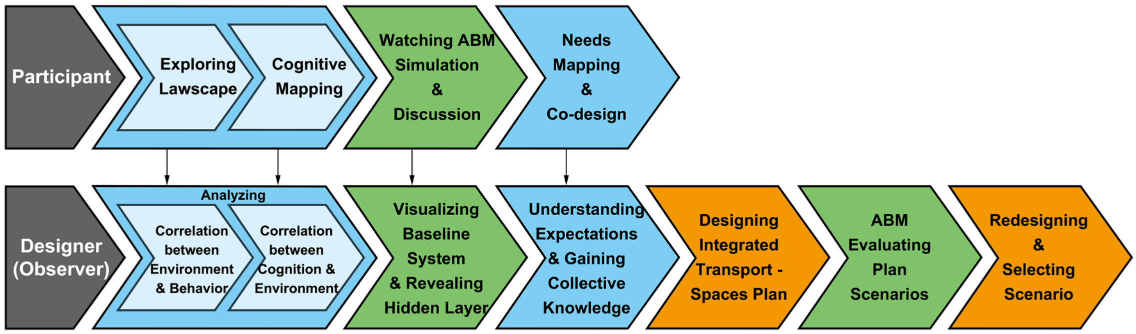

Fig. 3 A flow chart of engagement with the public using serious games and agent-based models, with displaying the actions of participants and research aims of urban designers (acting as observers during the game). The color of each block reflects its corresponding meanings in Fig. 1

Integrating agent-based modeling, serious gaming, and co-design

Figure 1 shows the conceptual model applied in this research, a "Banana" model, which combines the approaches of agent-based modeling, serious gaming, and co-design. From bottom to top in the illustration, games are conducted primarily to explore the association between human behavior and the built environment. By using methods of observation, interview, and drawings, qualitative data are collected during this procedure and then put into ABM via flow 1. Here, the data indicate the users' perceived environment that may assist modelers in representing an accurate TIPS system in the model. Such data also provide insights into crowd behavior and human needs that contribute to adjusting the behavioral rules of ABM. Moreover, games also gather information about citizens' expectations and ideas of changing the study area, which act as an inflow of "collective knowledge" (flow 2) to the co-design process.

Flows 3 and 4 display an iterative process from urban modeling to urban design. This process also combines with the co-design procedure in which simulation results can be shown to a range of decision-makers, who can then test potential interventions and design choices and receive feedback on this directly (Bunschoten 2018; Vainio 2016). Moreover, ABM supported by visualization tools can engage the game participants, educate them in understanding the latent social network, and facilitate conversations between participants. This feedback loop is represented by flow 5. Finally, there is a probable inflow of new urban plans to the game design process as shown in flow 6. For instance, it would be more participatory if game designers can show new planning scenarios and the projected simulation during the exhibition and interact with the actors, evaluating the alternatives in real-time. Since this study did not perform the final flow, it is represented as a dashed line in Fig. 1.

In Fig. 2, an integrated methodology for TIPS systems planning is presented with involving the steps in urban design and agent-based modeling; further information of the framework could be found in Yang et al. (2019). Apart from the flows shown in Fig. 1, this methodology links the expert design steps (i.e., context survey, problem analysis, scenarios design, redesign, plan selection) with simulation-based system examination and assessment steps. ABM is used to examine and simulate the status quo system as well as to test and assess different scenarios to support designers in selecting clear-cut plans.

Goals of engagement with the residents and exploration of their behavior in this project are attained through a three-step *Serious Game* that is supplemented by an *Agent-Based Model* visualization. All of these processes, shown in the first row of Fig. 3, provided qualitative data that contribute to examining the impact of the TIPS environment on human behavior and people's perception of their surroundings. The engagement also benefits the (re)design of the ABM as well as further understanding of the wishes of the individuals on local TIPSs. Supported by such data, the designers could draft targeted plans for the study area which are then tested and estimated by the model.

Serious game-step 1: Exploring Lawscape

In order to investigate the key indicators of the TIPS system impacts on crowd behavior, the first step of serious gaming is designed as a participatory experiment. Human behavior in complex urban systems emerges following a series of principles which are interpreted as law in the theory of *Lawscape* elaborated by Philippopoulos-Mihalopoulos (2014). Here, law[1] is considered in its broader meaning, namely not just state and text-based law, but also embodied and material law, as well as general normativity and behavior. In order to break down the observation of the Lawscape into more

[1] The Oxford Dictionary defines law as "The system of rules which a particular country or community recognizes as regulating the actions of its members and which it may enforce by the imposition of penalties." It is demonstrated that the law not only refers to "statute law and the common law," but also has a broader meaning of "something regarded as having binding force or effect."

manageable units, the Lawscape is split into three aspects: the "symbolic" (e.g., road signs), the "material" (e.g., bollards) and the "atmospheric" (e.g., the tension of two conflicting neighborhoods) (Barnett et al. 2017). In this experiment, the voluntary participants were requested, first, to comply with the "symbolic" Lawscape, to break the restrains of the "material" Lawscape, and to attempt to construct a space of spatial justice (a just "atmosphere" of collaboration and negotiation), which different users could share without conflict. Data were collected by employing both digital technologies (such as documentary, social media posts, and GPS tracking) and traditional sociological research methods (such as observation and documentation).

Serious game-step 2: Cognitive mapping

After exploring the built environment, the participants were then asked to draw a cognitive map of the area for revealing the perceived TIPS system in human minds. Lynch (1960) put forward the concept of *Cognitive Map*, which is rooted in the theory of environmental psychology, and pointed out that five key elements construct people's image of a city. One of them is "nodes" which could enhance social encounters, and the most representative "node" is public spaces. Two other elements, "paths" and "edges," may cause social cohesion and segregation at a neighborhood scale. Interestingly, transport infrastructure that takes the role of "path" at a city scale could also become an "edge" in neighborhoods. For instance, a river could be a "path" for inter-city or inner-city shipping but also an "edge" separating different neighborhoods. Consequently, the assembled cognitive maps are beneficial for designers to figure out and repurpose the transport infrastructural "edges," to optimize the intensively used public "nodes" and transport "paths" through the lens of user perceptions.

Serious game-step 3: Needs mapping and co-design

Based on an awareness of the Lawscape, the personal cognitive maps, and the hidden social layer (revealed by the ABM), the public was invited to write down their needs and wishes on a map. These mapping data are a significant source of input for the "problem analysis" step in urban design (see Fig. 2, top-left corner). *Human Needs* theories, evolved from psychological studies of human behavior, have been introduced into urban design and planning practices to balance the conflicts between economic development and quality of life. It is proved that human needs-based construction provides opportunities for sustainable development (Jackson et al. 2004; Steinfeld and Maisel 2012). Therefore, the qualitative data yielded from human needs mapping could support sustainable TIPS planning. Aiming at inspiring the individuals' design capabilities and assembling the collective creativity, we asked them to present their design directly on the physical settings, e.g., drawing on the roads using chalks.

Agent-based model

In an attempt to get more input from the residents and visitors, an exhibition equipped with a video of an agent-based simulation model was performed which triggered intense discussions among the audience. Simultaneously, interviews with the game actors were carried out. Such an interactive interview inspired participants to think of the social layer (e.g., crowd behavior) under the physical environment, which they had explored in the first two steps of the game, and therefore stimulated them to consider the overall social requirements when satisfying their own needs. Here, an early prototype of the ABM gave the public an impression of how the model could help designers and what the locals and visitors could get out of this.

The model was adapted from the Smart-City Model demonstrated in (Bustos-Turu 2018; Yang et al. 2019; Van Dam et al. 2017), which includes a road network layer and a land use layer in GIS, and heterogeneous agents with their activity profiles. In earlier work, a synthetic population was generated to represent the entire population. Using socio-demographic data (e.g., household size), and geographical data from the local government, agents were created randomly according to the population density of each residential land. Afterwards, an activity schedule (i.e., the time-specific sequence of human activities) in a weekday was assigned for agents which differ among workers, non-workers, and visitors. Here, human activities were categorized referring to the three kinds of basic human needs, i.e., personal, social, and ecological needs (Mallmann 1980). Five types of agent activities—residential, industrial, commercial, cultural, and leisure activities—were also attached as a parameter to the land use layer. Furthermore, a pavement network was provided to agents for transport. On this basis, agents firstly choose an activity schedule, and then find a series of locations to visit according to the activities provided by each place. To travel from the origins to destinations, agents choose the shortest route over the road layer.

Case study: London Hackney Wick

In July 2017, a team of researchers and practitioners came together to embark upon a month-long situated research residency based at Arebyte Gallery in Hackney Wick, East London. Connecting visual, digital, and performance art practices with contemporary scientific research, law, and urban design, the Crowd Control project explored the mechanisms of collective behavior through observation, simulation, and

Fig. 4 The case study site, including the Hackney Wick neighborhood and a part of Queen Elizabeth Olympic Park in London. Adapted from Google map

experimentation (Barnett et al. 2017). Arebyte commissioned the project as part of their 2017 Arts Council England funded program on "systems of control," inviting artist Heather Barnett to take a month-long residency at the gallery. Extending the invitation, Heather was joined by Andreas Philippopoulos-Mihalopoulos for his contributions on law and spatial justice. The project included a series of spatial games and experiments, as well as site-specific art shows. The output of interest here is the experimental game *Escaping the Lawscape* as thought by Andreas Philippopoulos-Mihalopoulos and Liu Yang, in collaboration with artist Julius Colwill.

Hackney Wick is located close to London's Queen Elizabeth Olympic Park (see Fig. 4). The region has undergone dramatic ecological, economic, and social changes accompanied by conflicts between "development and protection," "outsiders and insiders" in the process of transforming from an industrial zone into a vibrant community of artists and residential areas. The area has changed and gentrified rapidly with new housing developments and investments in public space, partly as an effect of the Olympic Park developments, which leads to fears that the existing community will be priced out. The site contains a mixed type of transport infrastructures: a railway line and a station, canals, mix-used streets, and paths (for cyclists and pedestrians without separated cycling lanes). Mainly, there are four types of public space here: (1) the Olympic Park for cultural-leisure usage, (2) the Victoria Park for leisure usage, (3) canal-side restaurants and bars for commercial usage, and(4) locations along the canal for leisure usage, in addition to some small squares and city greens throughout the area.

Serious game-step 1: Escaping the Lawscape

As a part of the Crowd Control project, an experiment entitled *Escaping the Lawscape* was carried out on two groups of people (50 local residents, divided into small groups of 3–4) in 2 days, preceded by game-testing activities over different groups of volunteers over 2 days. The experiment had not done before in the specific format. The experiment was designed as three stages. Firstly, search and document (by uploading on dedicated social media platforms) signs of the Lawscape and hyper-comply with them by exaggerating their legal demands; say, sign reading STOP, and everyone had to stop doing what they were doing. Secondly, search and document (through uploading on dedicated social media platforms) signs of the Lawscape and resist their demand.

Fig. 5 *Escaping the Lawscape* experiment: Participants were breaking the restrains of material. Copyright: Luka Radek

Finally, occupy a space (a real legal case locus of the Gainsborough School Bridge linking the school across the canal, access to which was disputed by various sides) and explore the possibilities of spatial justice.

Figure 5 shows the participants were trying to pass over a fence when they were asked to break the rules of the material Lawscape. Eleven participants posted their group findings of the symbolic and material Lawscape in Hackney Wick on Twitter, Facebook, and Instagram. On the whole, 23 posts related to the participants' hyper-compliance behavior, and 26 posts depict how they resisted the Lawscape. It is evident from the posts that the symbolic Lawscape of signs (including road signs, caution/warning signs, information boards) instruct, prohibit, or direct individuals' movement. The material Lawscape of roads (including the surface, curbs, bollards) could separate different road users and direct walking behavior. Public spaces (the floor, slides, benches, walls with graffiti) along with plants could attract people to stand, sit (even lie down), and do recreational activities.

Therefore, it could be concluded that human behaviors are instructed, restricted, and directed by the transport-public space system through the design of signs, roads, public spaces, and vegetations. On the other hand, human behaviors also have impacts on the transport-public space system that individuals may not use public space in the way inscribed by the designers. For instance, the participants may perceive the streets as a place for lying down, benches for standing on, and fences for climbing. These behaviors will probably break the symbolic law, damage public facilities, and even lead to a redesign of the system.

Serious game-step 2: Cognitive mapping

The participants' cognitive maps indicate that the canal in the site, the River Lee, and the bridges over it form a fundamental structure of people's image of this area. They act as both edges and paths between blocks (see Fig. 6 as an example). Interestingly, the accessible bridges over and boats on the water could also be public spaces, i.e., nodes in the site. Some people outlined the open areas and restaurants along the river in their maps that tend to take transport infrastructure and linear urban spaces as a holistic system. It is worth noting that though the railway is a huge construction that could have attracted people, it did not appear in the cognitive maps. This may be due to the lack of accessibility and directivity of the under-constructed train station, which does not have a distinct entrance.

Watching agent-based simulation and interviews

Current visualization techniques tested in this area around Queen Elizabeth Olympic Park focus on displaying the physical layer, such as the interactive digital maps created for the Park (Parkmap). However, the ABM simulation in our project reveals the social layer by visualizing pedestrian movement. Based on the adapted Smart-City Model mentioned above, this model used socio-demographic data provided by the Hackney Wick Council and geographical data from Ordnance Survey through an online map and data delivery service (Digimap). The prototype of the model is a representation of the status quo TIPS system and was displayed on a large screen in the exhibition space (see a snapshot in Fig. 7). Figure 8 presents an interactive interview performed during watching simulation animation. One member of the audience said "I never thought about people's movement in this area. Every Londoners live their own lives and even does not know their neighbors. The computer model shows me a hidden Hackney Wick." Players talked over with each other about the on-screen places (the green parts in Fig. 7) they have just visited and found it quite vivid to see their walking behaviors being represented by the movement of orange cubes in the simulation model.

Serious game-step 3: Needs mapping and co-design

Local residents and visitors wrote down their demands and anticipation on stickers using colorful pens and pasted them to specific places on two site maps, see Fig. 9 as examples.

To summarize, their needs and wishes for the TIPS system could be grouped into three types: (1) open public space, (2) streets and path, and (3) public amenities. Initially, they demanded more diverse types of open spaces along the river and main roads, such as public boats for meeting place, various kinds of plants, exercise facilities, shelters, and quiet location. As for the road network, it seems that canal-side paths were the most attractive but should be equipped with more street furniture and be more accessible to the entire neighborhood. A provision of bicycle infrastructures and safety improvement for different road users

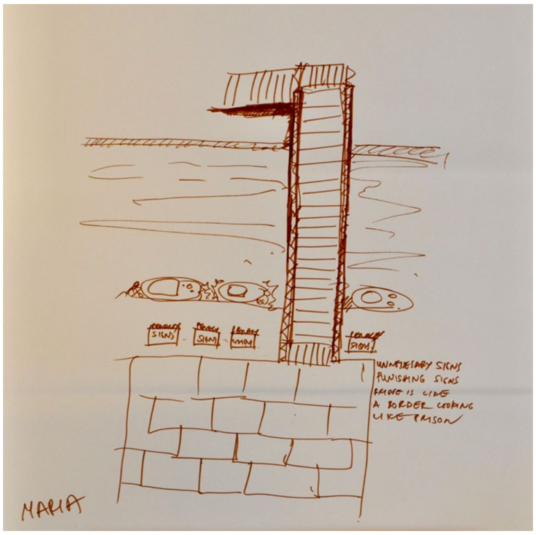

Fig. 6 Participants' cognitive mapping of the site

Fig. 7 A snapshot of the ABM simulation

were also highlighted. Finally, the users raised their need for both indoor and outdoor public amenities, such as indoor markets, outdoor cinema, public toilets, and restaurants. As a conclusion, the riverside areas are the most attractive part of the site that are expected to be more accessible, diverse, and safe. Moreover, two individuals commented on the railway line and the station, with requiring an increase in transparency and safety. The above needs and wishes were then positioned on data format shapefile for GIS software.

On the same physical maps, individuals were asked to draw their designs for the region. One of their creative ideas is to regard rivers as a public realm to enhance social cohesion. Furthermore, the players are asked to design directly on the field using colorful chalks. Figure 10 shows a participant who was trying to create a sense of spatial justice on a crowded riverside path.

Afterwards, we performed an online survey as a retrospective study to understand how the participants heard about this project and related activities, whether it met their expectation, and what did they gain by attending/what did they like most. We received four answers to the final question, listed as below:

> *It was nice chatting to the other people, looking at London in a slightly different way…*
> *Learnt a new technique for engaging my students on field trips…*
> *The insight, the experiential learning, the way the games made people wear many hats and see the world from different points of view.*
> *I enjoyed meeting new people, two of which I am still in touch with … learning a bit more about Lawscape.*

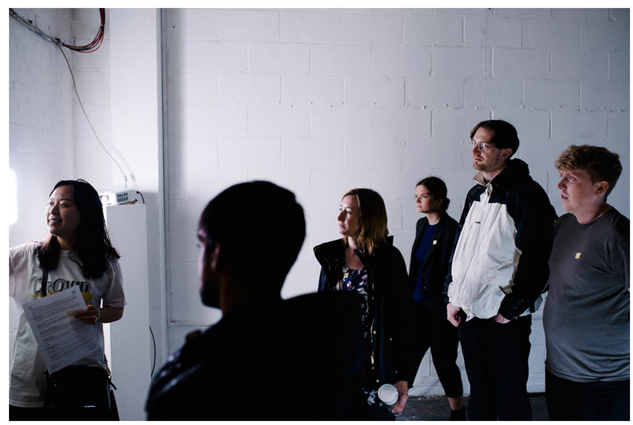

Fig. 8 Engagement with participants using ABM. Copyright: Luka Radek

Urban design – ABM evaluation – Redesign

In view of the above, a new Hackney Wick design was generated by utilizing both the qualitative data gathered from the public (the aforementioned three types of needs and wishes) and the expertise of urban designers. In the baseline scenario (see Fig. 11), there is only one street along the canal—on the right side. In the integrated design scenario (see Fig. 12), we increased the connectivity between the river and neighborhoods by adding new riverside trails and bridges. To quantitatively analyze the pedestrian network *Connectivity*, we calculated the *Connected Node Ratio* (*CNR*) of the road network in GIS which is defined as follows (De Nazelle 2007; Dill 2004):

(a) **(b)**

Fig. 9 Participants' needs and wishes mapping: **a** Map 1. **b** Map 2

$$\text{CNR} = \frac{\text{The number of intersections}}{\text{The number of intersections} + \text{the number of dead ends}} \times 100\%,$$

where a higher value of CNR means that there are relatively few dead-end streets, and probably a higher level of connectivity. The CNR in the base case is 98.03%, while that of the plan I is 98.10%. Simultaneously, the current riverside leftover spaces were changed into accessible multi-purpose places on the land use GIS layer to meet the needs of Café, restaurants, greenery, etc.

Afterwards, ABM simulation was utilized to evaluate different scenarios. One evaluation example is *pedestrian demand* estimation, which is a key indicator of active travel planning. Figure 13 shows the simulated travel needs of the base case and Fig. 14 displays that of the integrated design I. The two figures visualize pedestrian demand through the shade of red lines (representing road lanes), i.e., the darker the red, the more demand on that lane. Apparently, in this integrated scenario, people would more likely go to the riverside. Another investigated domain is the agents' *occupancy of public spaces and public buildings*. In the same figures, the result of occupancy was displayed through the shade of green tracts (representing the public areas), i.e., the greener places are more used.

By comparing the results, it can be found that the two schemes only differ slightly. This may because these repurposed open places are too small compared to the existing dominant open spaces such as the Victoria Park. This finding is consistent with the work of Sugiyama et al. (2010), which indicated that increasing the size and attractiveness of certain public places is more significant than just raising the number of open spaces. In this respect, we then redesigned the integrated plan.

To make the canal-side areas more attractive, in scenario II (see Fig. 15), a continuous linear public space system was designed alongside the water. Such a system consists of multi-use public buildings, gardens, and public use boats. Additional streets were built to join the cul-de-sacs on the south of the river, and the CNR in this scenario rose to 98.19%. As shown in Fig. 16, the canal-side places in this revised plan appeal to pedestrians. A detailed analysis of people's daily use of each public buildings and civic spaces could be found in Figs. 17 and 18.

Fig. 10 Participants' redesign of a path to create sexual justice in civic spaces

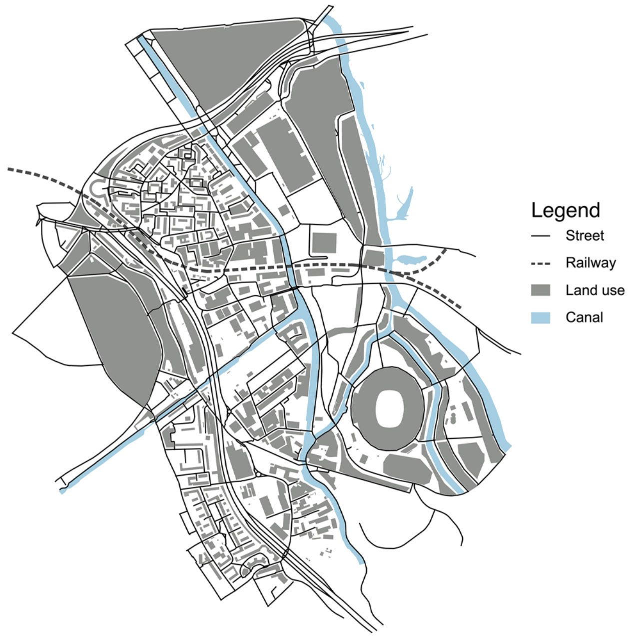

Fig. 11 Baseline plan of the study area

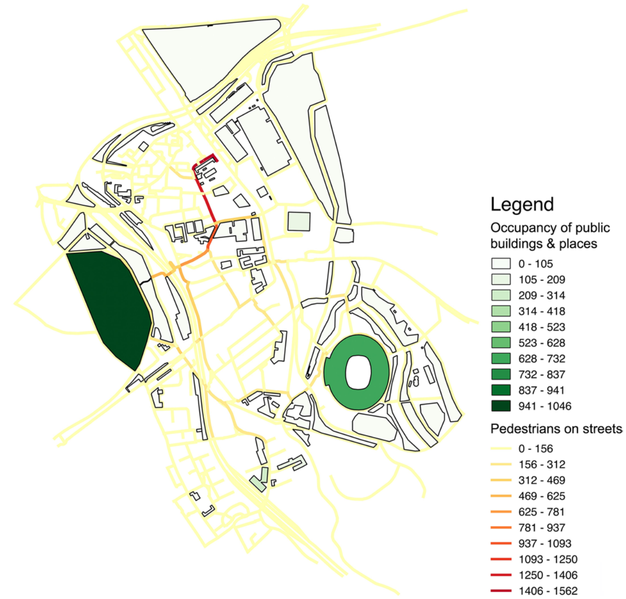

Fig. 13 ABM evaluation of the baseline scenario

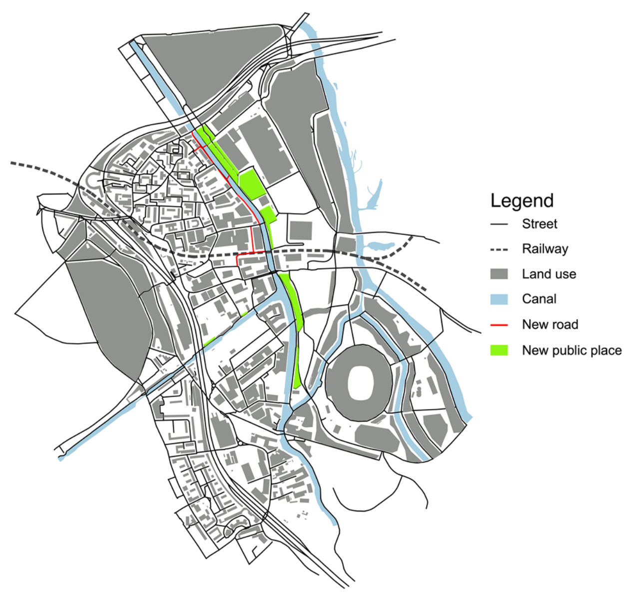

Fig. 12 An integrated plan I of the study area

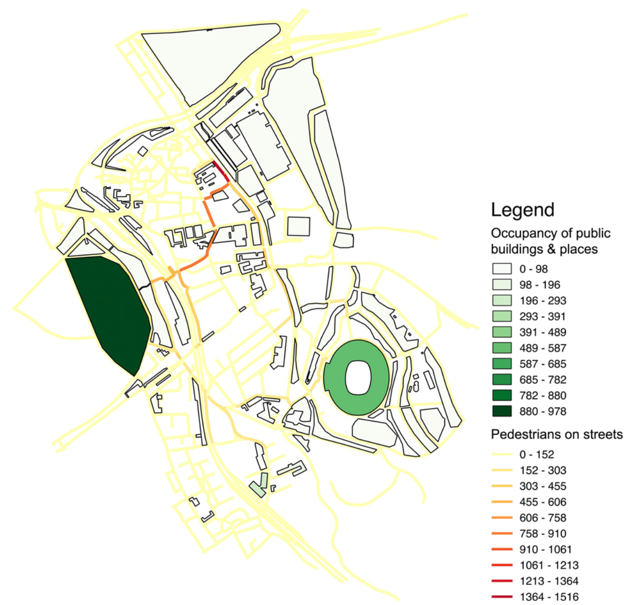

Fig. 14 ABM evaluation of the integrated plan I

In Fig. 17, the violet plot areas represent public places and the citizens' usage of each area was displayed by the clock faces on it which are divided into 24 equal parts (indicate the 24 h)—the black half indicates night time and the white half means day time. The radius of the clock face means the number of users, and the vertex of the yellow-blue polyline signifies the number of people staying there at the corresponding time. Furthermore, we could get insights into the most appealing places by comparing the radius of the dials. As shown in Fig. 18, the six most attractive sites feature a highly mixed land use, i.e., an assembly of commercial (com), industrial (ind), culture (cult), leisure (leis), and residential (res) usage. A well-connected and accessible public space system is also capable of raising the popularity of new areas. The simulation model can thus be used to experiment with different designs of the built environment.

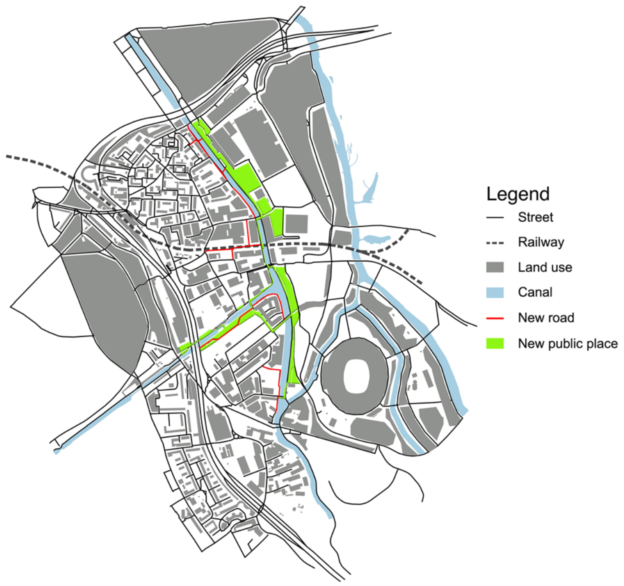

Fig. 15 An integrated plan II

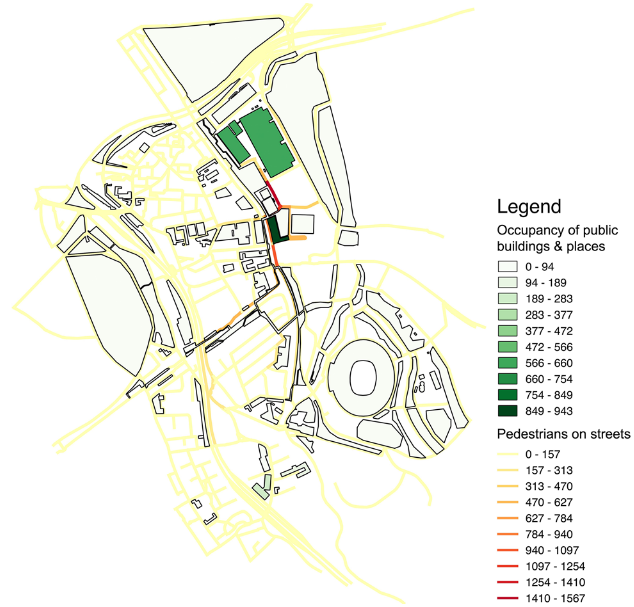

Fig. 16 ABM evaluation of the integrated plan II

Discussions

With the basic ABM implemented and shown to the citizen at an exhibition as part of the Crowd Control project, qualitative information was acquired that can be incorporated into the model. Continuing research will optimize the model from three aspects: (1) a refined model of the human behavior in spaces for route selection, (2) more realistic destination choices and activity schedules, and (3) agents' detailed response to the Lawscape such as signposts and street furniture. This section explores firstly how this could be achieved.

Cognitive maps, drawn by participants, represent their view of the district while the simulation model uses the real geographic location of buildings and infrastructure. The cognitive mapping, thus, reveals how those on the ground see these locations, distances, and barriers and how human recognition system is different from the simple shortest-path algorithm (based on Dijkstra's algorithm Skiena 1998) employed in the model currently. To take this into account, the pathfinding algorithm could be updated to not only consider distance (or travel time) but add additional factors that represent the ease of using a route and attractiveness of the space. This index can be added as attributes to the road layer which is read during initialization of the ABM, and the pathfinding algorithm updated accordingly.

The cognitive maps also tell us that the location assignment algorithm, used in the model to link activity with a location on the map, should be improved and that we need an additional weighting parameter to favor central locations identified by participants over less attractive nodes. Activity schedules play a significant role in the ABM, as they generate the start and end point of journeys over the transport network. In the current work, surveys were only used to collect the participants' comments on the experiment; in future, however, additional surveys could be conducted to understand individuals' activity schedules. In such, we would no longer have to use only a high-level schedule based on generic time use surveys which include waking/sleeping patterns and commuting times but can tailor this to the location. A challenge remains in getting a representative sample as the number of participants was small compared with the population of the area, not to mention visitors from outside. However, the already collected data will be an improvement which can be refined in further settings if needed. Calibration with measured data (e.g., GPS trajectories got during the *Escaping the Lawscape*) can further support this work.

The serious games signified another gap in the current model, namely that details in the infrastructure such as street furniture, vegetation and wayfinding signs which all play a crucial role in how some people navigate and use the space, particularly for recreational walking (when shortest route is less important). The model currently does not represent this kind of behavior, and this is also the most difficult to incorporate. One way of doing this is to have different agent classes. One class symbolizes people who are thoroughly familiar with the local infrastructure (residents and regular commuters) and make decisions based on path length. The other class represents those who are unfamiliar and rely more on queues and nudges in the infrastructure to choose their routes and destinations. The second class would not be as dependent on activity schedules so another module needs to be designed which will simulate the agent's decisions

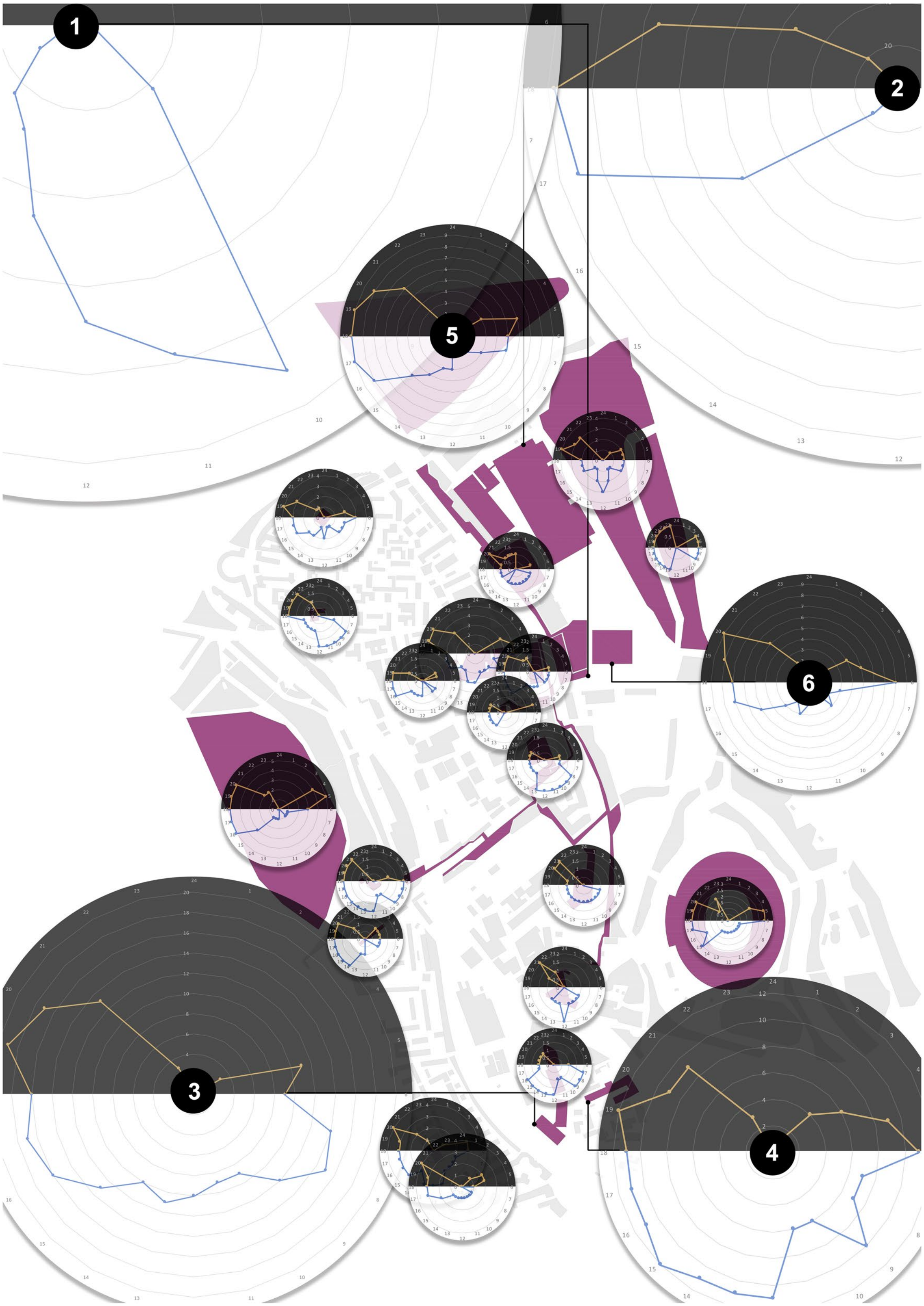

Fig. 17 An illustration of using ABM to predict the use of public spaces and public buildings during a workday

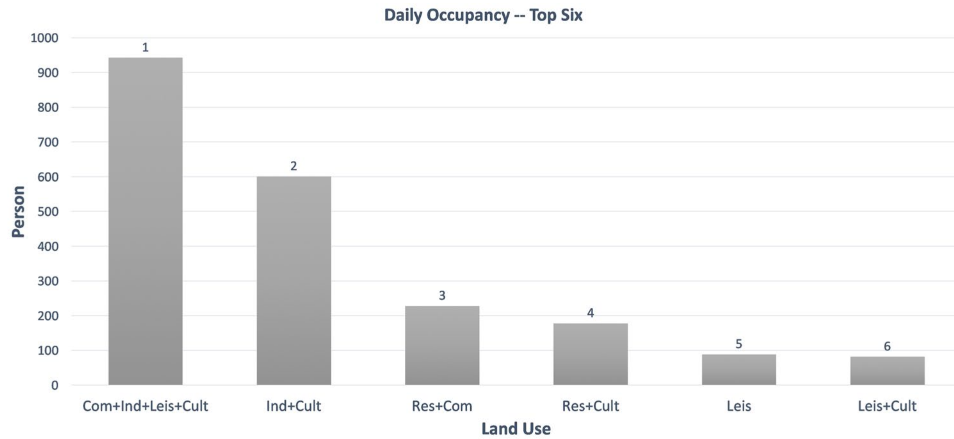

Fig. 18 Functions of the most attractive public spaces and buildings under the integrated design scenario II

mechanism on exploring the city. Apart from the insights about model optimization, more lessons could be extracted from the case study.

On the one hand, based on the feedback from participants, the demonstration of a social simulation model to the participants accompanied by a series of participatory games proved to be an effective way to engage and inspire the public and to encourage them to share their thoughts. In addition, the three-step gaming reveals how private or privatized properties interfere with both the residents' actual movement, their sense of belonging, and community cohesion. For example, the Gainsborough School Bridge though being one of the main pedestrian arteries crossing the river was closed to the public at the time of the experiment. This was particularly evident in the "atmospheric" stage of the *Escaping the Lawscape* game, where the space of justice was proven elusive.

On the other hand, the simulation results indicate that increasing the street connectivity and providing more public spaces alone can hardly attract people to walk to or attend recreational activities in these new places (the integrated plan I). In an attempt to build an attractive and pedestrian-friendly TIPS system, a holistic strategy is needed which includes an increase of street connectivity and public space accessibility, in line with providing a series of well-designed public spaces that are continuous, networked, and mixed-use (the integrated plan II).

Finally, the integrated design methodology proposed in this study turns out to be a valuable decision-support tool for designing integrated TIPS systems. The method allows design experts to take advantage of the qualitative data deduced from public engagement activities and the quantitative estimations generated by agent-based modeling in problem analysis and plan evaluation. On this basis, they can utilize their expertise in urban design to draft targeted scenarios. For example, the model helps designers estimate the use of streets by pedestrians and the potential use of public spaces during a day in a planned TIPS system.

Conclusion

We have presented a new joint methodology that integrates agent-based modeling and serious gaming with a co-design approach to involve citizens into the design of an integrated TIPS system. By conducting a three-step serious game and a prototype ABM visualization, this study achieves the goals for collecting public ideas on the needs and wishes for the existing TIPS system, and for gaining insights of users behavior in open spaces and mobility infrastructures. Following the research on ABM-aided and participatory design, our study further indicates that game-informed ABM simulations are compelling tools for evaluating various urban design alternatives and engaging the users into the design process. In a case study in London Hackney Wick, the iterative model development and early prototyping proves successful and holds opportunities for building more realistic social simulation models in the next phase. In addition, by estimating the walking demand and public space usage under different integrated plans, the simulation model shows that a holistic and systematic strategy is needed for building an attractive and walkable TIPS system. We expect this coupled Design–ABM–Game method to open up a new way of co-design creating walkable, aesthetic, and connected urban transport networks and public space systems for motivating healthier behavioral changes in urban areas.

Acknowledgements The research is based on a Joint-PhD Program between the University of Chinese Academy of Sciences (UCAS) and Imperial College London (ICL) and partially supported by a Scholarship offered by the UCAS. The authors appreciate the support from Dr. Arnab Majumdar and Prof. Washington Ochieng from the Centre for Transport Studies, ICL, and the assistance of Ms. Heather Barnett and Mr. Julius Colwyn in organizing the Escaping Lawscape experiment of the Crowd Control project. Specifically, the authors thank Dr. Wander Jager for giving insightful comments to improve the paper. An earlier version of this paper was presented at the Social Simulation Conference 2018 in Stockholm. We thank for all the suggestions given by our reviewers and the conference participants. Van Dam is supported by the EIT Climate-KIC project Smart District Data Infrastructure.

References

Al-Kodmany, K. 1999. Using visualization techniques for enhancing public participation in planning and design: Process, implementation, and evaluation. *Landscape and Urban Planning* 45: 37–45.

Barnett, H., L. Cappelatti, J. Colwyn, D. Georgopoulou, J. Greenfield, A. Philippopoulos-Mihalopoulos, D. Strömbom, and L. Yang. 2017. Crowd Control. *Interalia Magazine.* https://www.interaliamag.org/articles/heather-barnett/. Accessed 18 Feb 2020.

Bertolini, L., F. Le Clercq, and L. Kapoen. 2005. Sustainable accessibility: A conceptual framework to integrate transport and land use plan-making. Two test-applications in the Netherlands and a reflection on the way forward. *Transport Policy* 12: 207–220.

Bonabeau, E. 2002. Agent-based modeling: Methods and techniques for simulating human systems. *Proceedings of the National Academy of Sciences of USA* 99: 7280–7287.

Buchanan, P. 1988. What city? A plea for place in the public realm. *The Architectural Review* 184: 31–41.

Bunschoten, R. 2018. *From smart city to conscious city. In Handbuch Energiewende und Partizipation*. Wiesbaden: Springer.

Bustos-Turu, G. 2018. Integrated modelling framework for the analysis of demand side management strategies in urban energy systems. PhD Thesis. *Imperial College London*.

Cervero, R. 2009. Transport infrastructure and global competitiveness: Balancing mobility and livability. *The Annals of the American Academy of Political and Social Science* 626: 210–225.

Chisholm, J. 2017. *What is co-design*. Design for Europe. https://designforeurope.eu/what-co-design. Accessed Aug 2019.

De Nazelle, A. 2007. *Risk assessment of a pedestrian-oriented environment.* Doctoral Dissertation, The University of North Carolina at Chapel Hill.

De Nazelle, A., M.J. Nieuwenhuijsen, J.M. Antó, M. Brauer, D. Briggs, C. Braun-Fahrlander, N. Cavill, A.R. Cooper, H. Desqueyroux, and S. Fruin. 2011. Improving health through policies that promote active travel: A review of evidence to support integrated health impact assessment. *Environment International* 37: 766–777.

Dia, H. 2002. An agent-based approach to modelling driver route choice behaviour under the influence of real-time information. *Transportation Research Part C: Emerging Technologies* 10: 331–349.

Digimap. *Ordnance Survey data*. https://digimap.edina.ac.uk/os. Accessed 6 April 2018.

Dill, J. 2004. Measuring network connectivity for bicycling and walking. In *83rd Annual meeting of the Transportation Research Board*, 2004 Washington, DC, 11–15.

Duke, R.D. 1980. A paradigm for game design. *Simulation and Games* 11: 364–377.

Edmonds, B. 2017. Five modelling purposes. In *Simulating Social Complexity—A handbook*, 2nd edn, eds., B. Edmonds and R. Meyer. Berlin: Springer.

Edwards, V.M., and S. Smith. 2011. Lessons from the application of decision-support tools in participatory management of the New Forest National Park, UK. *Environmental Policy and Governance* 21: 417–432.

Escobar-Castillejos, D., J. Noguez, L. Neri, A. Magana, and B. Benes. 2016. A review of simulators with haptic devices for medical training. *Journal of Medical Systems* 40: 104.

Ewing, R., and R. Cervero. 2010. Travel and the built environment: A meta-analysis. *Journal of the American Planning Association* 76: 265–294.

Gilbert, N. 2007. *Computational social science: Agent-based social simulation. In Agent-based modelling and simulation*. Oxford: Bardwell.

Gilbert, N., and K. Troitzsch. 2005. *Simulation for the social scientist*. London: McGraw-Hill Education.

Gosen, J., and J. Washbush. 2004. A review of scholarship on assessing experiential learning effectiveness. *Simulation and Gaming* 35: 270–293.

Hahn, H.A. 2013. The conundrum of verification and validation of social science-based models. *Procedia Computer Science* 16: 878–887.

Hanzl, M. 2007. Information technology as a tool for public participation in urban planning: A review of experiments and potentials. *Design Studies* 28: 289–307.

Jackson, T., W. Jager, and S. Stagl. 2004. *Beyond insatiability: Needs theory, consumption and sustainability*. ESRC Sustainable Technologies Programme Working Paper Series 2.

Jahangirian, M., T. Eldabi, A. Naseer, L.K. Stergioulas, and T. Young. 2010. Simulation in manufacturing and business: A review. *European Journal of Operational Research* 203: 1–13.

Kelly, H., K. Howell, E. Glinert, L. Holding, C. Swain, A. Burrowbridge, and M. Roper. 2007. How to build serious games. *Communications of the ACM* 50: 44–49.

Lee, Y. 2008. Design participation tactics: the challenges and new roles for designers in the co-design process. *Co-design* 4: 31–50.

Liao, C., Y. Lin, and P. Barooah. 2012. Agent-based and graphical modelling of building occupancy. *Journal of Building Performance Simulation* 5: 5–25.

Lynch, K. 1960. *The image of the city*. Cambridge: MIT Press.

Macal, C.M. 2016. Everything you need to know about agent-based modelling and simulation. *Journal of Simulation* 10: 144–156.

Mallmann, C. 1980. Society, needs and rights: A systemic approach. In *Human Needs: A contribution to the current debate*: 37–54. Cambridge: Oelgeschlager, Gunn and Hai.

Manzini, E. 2015. *Design, when everybody designs: An introduction to design for social innovation*. Cambridge: MIT Press.

Maoh, H., and P. Kanaroglou. 2009. A tool for evaluating urban sustainability via integrated transportation and land use simulation models. *Urban Environment* 3: 28–46.

Mayer, I.S. 2009. The gaming of policy and the politics of gaming: A review. *Simulation and Gaming* 40: 825–862.

Meadows, D.L. 1999. Learning to be simple: My odyssey with games. *Simulation and Gaming* 30: 342–351.

Moughtin, C. 2003. *Urban design: Street and square*. Oxford: Architectural Press.

Nieuwenhuijsen, M.J., H. Khreis, E. Verlinghieri, N. Mueller, and D. Rojas-Rueda. 2017. Participatory quantitative health impact assessment of urban and transport planning in cities: A review and research needs. *Environment International* 103: 61–72.

Parkmap. *Park Living Map*. https://parkmap.livingmap.com/?zoom=13&lon=-0.01651009360558059&lat=51.539351925165846&overlay=&interest=&interestTypes=&gid=ax537659ay184078#. Accessed 21 March 2019.

Philippopoulos-Mihalopoulos, A. 2014. *Spatial justice: Body, lawscape, atmosphere*. London: Routledge.

Ravazzoli, E., and G.P. Torricelli. 2017. Urban mobility and public space. A challenge for the sustainable liveable city of the future. *The Journal of Public Space* 2: 37–50.

Raybourn, E.M. 2007. Applying simulation experience design methods to creating serious game-based adaptive training systems. *Interacting with Computers* 19: 206–214.

Robinson, D.T., D.G. Brown, D.C. Parker, P. Schreinemachers, M.A. Janssen, M. Huigen, H. Wittmer, N. Gotts, P. Promburom, and E. Irwin. 2007. Comparison of empirical methods for building agent-based models in land use science. *Journal of Land Use Science* 2: 31–55.

Ruiz-Apilánez, B., K. Karimi, I. García-Camacha, and R. Martín. 2017. Shared space streets: Design, user perception and performance. *Urban Design International* 22: 267–284.

Sanoff, H. 1990. *Participatory design: Theory and techniques*. Raleigh: Henry Sanoff.

Skiena, S.S. 1998. *The algorithm design manual*. New York: Springer.

Smith, R. 2010. The long history of gaming in military training. *Simulation and Gaming* 41: 6–19.

Steinfeld, E., and J. Maisel. 2012. *Universal design: Creating inclusive environments*. Hoboken: Wiley.

Sugiyama, T., J. Francis, N.J. Middleton, N. Owen, and B. Giles-Corti. 2010. Associations between recreational walking and attractiveness, size, and proximity of neighborhood open spaces. *American Journal of Public Health* 100: 1752–1757.

UN-Habitat. 2016. Urbanization and development emerging futures. *World cities report.*

Unity. *Unity Technologies—Game engine, tools, and multiplatform*. https://unity3d.com/es/unity. Accessed 6 Aug 2019.

Vainio, T. 2016. Motivations, results and the role of technology in participatory design research during 2000's—A review in the field of architecture and urban planning. *Architecture and Urban Planning* 11: 14–18.

Van Berkel, D.B., and P.H. Verburg. 2012. Combining exploratory scenarios and participatory backcasting: Using an agent-based model in participatory policy design for a multi-functional landscape. *Landscape Ecology* 27: 641–658.

Van Dam, K.H., D. Koering, G. Bustos-Turu, and H. Jones. 2014. BOTH Agent-based simulation as an urban design tool—Iterative evaluation of a smart city masterplan.

Van Dam, K.H., G. Bustos-Turu, and N. Shah. 2017. A methodology for simulating synthetic populations for the analysis of socio-technical infrastructures. In *Advances in social simulation 2015*, ed. W. Jager, R. Verbrugge, A. Flache, G. De Roo, L. Hoogduin, and C. Hemelrijk, 528. Springer.

Van Os, M. 2012. *Using gaming as a data collection tool to design rules for agents in agent-based models.* MSc Thesis, Delft University of Technology.

Waldheim, C. (ed.) 2012. *The landscape urbanism reader*. Chronicle books.

Yang, L., K.H. Van Dam, L. Zhang, and A. Philippopoulos-Mihalopoulos. 2018. Using qualitative data from resident engagement in a simulation model to inform urban transport and public space design in Hackney Wick. presented in *Social simulation conference 2018.*

Yang, L., K.H. Van Dam, B. Anvari, and A. De Nazelle. 2019. Simulating the impact of urban transport infrastructure design on local air quality in Beijing. In *Social simulation for a digital society: Applications and innovations in computational social science*, ed. D. Payne et al., Springer.

Yigitcanlar, T., and M. Kamruzzaman. 2014. Investigating the interplay between transport, land use and the environment: A review of the literature. *International Journal of Environmental Science and Technology* 11: 2121–2132.

Zhang, Q., E.H.K. Yung, and E.H.W. Chan. 2018. Towards sustainable neighborhoods: Challenges and opportunities for neighborhood planning in transitional urban China. *Sustainability* 10: 406.