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DOI
10.1080/1573062X.2023.2284958

Publication date
2023

Document Version
Final published version

Published in
Urban Water Journal

Taylor & Francis
Taylor & Francis Group

Urban Water Journal

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/nurw20

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To cite this article: Jessica Nguyen, Aashna Mittal, Zoran Kapelan & Lisa Scholten (30 Nov 2023): SuDSbury: A serious game to support the adoption of sustainable drainage solutions, Urban Water Journal, DOI: 10.1080/1573062X.2023.2284958

To link to this article: https://doi.org/10.1080/1573062X.2023.2284958

URBAN WATER JOURNAL
https://doi.org/10.1080/1573062X.2023.2284958

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RESEARCH ARTICLE

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SuDSbury: A serious game to support the adoption of sustainable drainage solutions

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ABSTRACT

There is an urgent need for urban environments to be flood resilient due to increasing urbanization and climate change. This can be addressed by adopting sustainable drainage solutions (SuDS) in households. However, lack of knowledge and awareness among urban residents is a barrier. In this paper, we present an educational serious game called SuDSbury to overcome this barrier and a pre-/post-game survey-based evaluation to study whether the game can educate citizens (and to what degree). An exploratory study with 14 players across three game sessions suggests that playing SuDSbury induced changes in knowledge, comprehension, and personal norms regarding SuDS. However, comprehension of concepts related to urban drainage can be improved by increasing game realism. The game should be further tested with a larger sample and a diverse demographic of urban residents. The participants further found that SuDSbury is fun and engaging to play, making it suitable for broader public interventions.

ARTICLE HISTORY
Received 1 November 2022
Accepted 8 November 2023

KEYWORDS
Sustainable urban drainage; serious gaming; education; pluvial flooding; evaluation

1. Introduction

Pluvial flooding[1] is a significant cause of devastation to urban settlements leading to economic losses and disruption to life (Jha, Bloch, and Lamond 2012). This issue is compounded by increasing urbanisation that promotes flooding by altering ground surfaces to obstruct natural drainage, resulting in greater and faster surface runoff. This also disturbs local water, soil and air quality (Kim, Kim, and Demarie 2017). In addition, drainage demands are growing due to climate change. Precipitation events are expected to become more frequent and intense (Seneviratne et al., 2021), particularly in northwest Europe, among other regions (Kyselý et al. 2011).

Traditional urban drainage systems rely on a centralized network of sewers to drain stormwater, but this approach has weaknesses that are becoming apparent due to more frequent pluvial flooding events and degradation of water quality (Nguyen et al. 2019). In contrast, sustainable urban drainage systems (SuDS[2]) aim to reduce the amount of runoff water that enters the underground drainage system by harvesting, infiltrating, slowing, storing, conveying, or treating the runoff on-site (Wood-Ballard et al. 2015). Typical examples of SuDS include green roofs, rainwater harvesting systems, permeable pavements, swales, bio-retention systems, pervious pavements, and wetlands among many others. In addition to reducing flood risk, SuDS offer many co-benefits such as reducing urban heat stress, improving air quality, and enhancing recreational spaces in urban areas (Li et al. 2020; Alves et al. 2019).

Since urban land cover typically comprises approximately 60% housing, urban residents have significant spatial opportunity to implement household-scale SuDS that can contribute towards urban climate adaptation. However, a lack of knowledge and awareness of SuDS (and hence indifference towards action) among urban residents has slowed widespread adoption (Nguyen et al. 2019; O'Donnell, Lamond, and Thorne 2017, Li et al. 2020; Roy et al. 2008, Li et al. 2020; Krijnen 2020; Winz, Trowsdale, and Brierley 2014; Wihlborg, Sörensen, and Alkan Olsson 2019).

To overcome the barrier of lack of knowledge and awareness, public intervention methods that engage and educate urban residents are recommended (Li et al. 2020; Thorne et al. 2018). Serious gaming is a medium where people can be engaged in an immersive manner to learn, develop, or practice a skill. The term *serious game* is defined in the context of educational gaming as, *'a game in which education (in its various forms) is the primary goal, rather than entertainment'* (Michael and Chen 2006, 17). In the water sector, gaming applications are increasing in popularity, creating an opportunity for the development of a serious game specific to SuDS issues (Aubert, Bauer, and Lienert 2018; Mittal, Scholten, and Kapelan 2022; Savic, Morley, and Khoury 2016).

In this paper, we present a serious game, SuDSbury, aimed at educating the public on household SuDS and increasing support for them. The game is targeted at general citizens with little to no background in SuDS and urban water management. The game's educational performance and its ability to increase support for SuDS were explored using a survey-based pre-/post-exposure evaluation approach.

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This article has been corrected with minor changes. These changes do not impact the academic content of the article.

Supplemental data for this article can be accessed https://doi.org/10.1080/1573062X.2023.2284958

2. Educating with a serious game

Hereunder, we briefly outline the educational and psychological frameworks used to design the educational serious game SuDSbury to educate the public about SuDs.

2.1. Serious games for education and raising awareness about SuDS

Serious games are effective in educating and raising awareness among people. They outperform traditional communication and education methods such as face-to-face teaching (de Freitas and Liarokapis 2011; Girard, Ecalle, and Magnan 2013; Zhonggen 2019). What makes serious games unique is their ability to motivate and engage people by providing challenges to overcome, autonomy to make decisions in the game, and the opportunity to relate to other players (Ryan, Rigby, and Przybylski 2006). Games can convey a complex system in a psychologically safe manner (Cheng and Annetta 2012; Lukosch et al. 2018) as they allow players to make mistakes, test alternatives and learn from failures (Plass, Homer, and Kinzer 2015). Another feature of serious games is their incorporation of incentive systems that enhance entertainment and stimulate motivation in the player, making them more receptive to the game's message and educational goals (Juan and Chao 2015; Plass, Homer, and Kinzer 2015).

Serious games are widely employed to educate and raise awareness about urban water management issues (see D'Artista and Hellweger 2007; Hirsch 2010; Appel et al. 2019; Rebolledo-Mendez et al. 2009; Novak et al. 2018; Pereira, Prada, and Paiva 2014 for examples). However, when it comes to SuDS, mostly non-gamified, interactive (web) applications are available. For example, the Climate Resilient City Tool (CRC) can be used for urban planning and climate adaptation where SuDS are placed in a digital map of a specific area and their impact on criteria such as additional storage capacity, heat reduction, costs, etc. are displayed (Deltares 2022; Van de Ven et al. 2016; Voskamp and Van de Ven 2015). Similarly, the web-based interactive tool ClimateScan conveys knowledge about various 'blue-green' projects implemented around the world (Tipping et al. 2015). We could not find any serious game to educate the public about household SuDS.

2.2. Knowledge gaps to be addressed in household SuDS adoption

The public's lack of knowledge about SuDS, its functions and the issues they tackle, is concerning given the significant portion of privately owned urban land. Bassone-Quashie (2021) found that the general public does not consider household SuDS because they are not aware of the increasing urban pluvial flood risk due to climate change and urbanisation, nor the urgency of climate adaptation. Information about the range of implementable household SuDS is also lacking. While the public recognises the value of large-scale SuDS, the impacts of small-scale, private household SuDS remain poorly understood (Buurman et al. 2021; Krijnen 2020). As water utilities or local public agencies commonly provide encompassing sanitary wastewater and stormwater drainage services, households' perceived responsibility typically ends with paying a tax or service fee (Dai, Wörner, and van Rijswick 2017; Krijnen 2020). Missing knowledge regarding the distinction between construction and maintenance costs of household SuDS acts as another barrier to adoption (Wihlborg, Sörensen, and Alkan Olsson 2019).

To increase public receptivity, it is also recommended to promote the multi-functional co-benefits of SuDS (Krijnen 2020; Thorne et al. 2018; Williams et al. 2019). These co-benefits include improvements to the environment (air quality, heat-stress reduction, carbon storage and sequestration), biodiversity (creating habitats, increasing diversity of plant and animal species), and water resources (improved runoff water quality, groundwater recharge) (Choi, Berry, and Smith 2021). For instance, Williams et al. (2019) found that residents living in proximity to SuDS highly valued the natural aesthetics and green space provided, leading to higher acceptance and willingness to pay for SuDS maintenance. To address the above aspects, household SuDS options like rain barrels, permeable pavements, rainwater retention ponds, green gardens, and green roofs were included in the game and information about their function, co-benefits, and construction and maintenance costs was provided.

2.3. Designing the serious game for behaviour change through education

To achieve the desired knowledge and attitudinal changes, it is advisable to use available pedagogical and behaviour change frameworks to design the serious game. The field of environmental psychology, which explores the relationship between human behaviour and the natural and built environment, is particularly relevant (Gifford 2014). The Stage model of Self-regulated Behavioural Change (SSBC) provides a comprehensive framework to conceptualise deliberative, pro-environmental behavioural change (Bamberg 2013). It incorporates behavioural theories such as the Theory of Planned Behaviour (TPB) and the Norm Activation Model (NAM) (for details see Keller, Eisen, and Hanss 2019). The SSBC breaks down an individual's process towards adopting a new behaviour into stages: pre-decision stage, pre-action stage, action stage, and post-action stage. Each stage consists of interacting variables and their causal relationships within and between stages.

For the purpose of the serious game presented in this paper, the pre-decision stage of the SSBC is the most relevant. During the pre-decision stage, a goal intention is formed as a result of various cognitive and affective changes. Goal intention serves as a pre-requisite for behavioural intention, where the individual forms a stance on a subject motivating and supporting a certain behaviour, expressed in statements such as 'I intend to reach this goal' or 'I intend to support X' (Bamberg 2013). It results from how one feels about a subject and one's personal norm. A personal norm refers to personally important moral standards that one desires to act in line with (Onwezen, Antonides, and Bartels 2013). Within the model, personal norms are influenced by perceived social norms, understanding the consequences of actions, feelings of responsibility, and negative emotions associated with the consequences of (not)

taking an action. In other words, according to the SSBC, a person's moral standards are shaped when the consequences of behaviours (perceived as good or bad) are understood, and the person accepts their personal responsibility to do the right thing and behave in a way to avert feelings of guilt and shame for causing harm (De Groot, Bondy, and Schuitema 2021).

Section 2.2 identified SuDS-related knowledge gaps regarding household SuDS, indicating low awareness of consequences and low ascription of personal responsibility, as well as a lack of social norms and personal norms for adopting SuDS. Without awareness of the issues and consequences of various urban drainage measures, an individual is unlikely to form goal intentions for change.

Thus, an intervention that educates urban residents about the consequences of climate change and urbanization on drainage and pluvial flood risk can equip them with the knowledge needed to form personal norms and goal intentions in the pre-decision stage of the SSBC. While the subsequent stages also play a role in SuDS adoption, the focus of our educational serious game intervention is on the pre-decision stage where we aim to influence personal norms to support adoption of household SuDS.

The pedagogical approach considers the Bloom et al. (1956) taxonomy of educational objectives which sets a hierarchical framework of six levels of thinking (Buchanan, Wolanczyk, and Zinghini 2011; Krathwohl 2002). The game primarily targets the lower levels of *knowledge* and *comprehension*, aiming to provide introductory and foundational knowledge about urban drainage and SuDS. Therefore, the main learning objective of the game is to increase *knowledge and comprehension of the effects of urbanisation and climate change on urban pluvial flood risk and the urgency for SuDS adoption (LO1.1)*. A secondary aim is to raise awareness of typical household SuDS functions and impacts to build confidence in decision-making when considering SuDS adoption. This is conveyed by the learning objective to achieve high *knowledge of household SuDS options and associated impacts (LO1.2)*.

3. Methodology

The methodology of this study features several stages described in this section that follows the structure shown in Supplementary Material A.

3.1. Serious game design

The serious game intends to represent a version of reality in the form of a simulation game. The development of a simulation game typically takes place in 5 phases (see Figure 1, Peters and Westelaken 2014; Mittal, Scholten, and Kapelan 2022). This design process is iterative and may require going back and forth between steps and phases to address all aspects of each phase.

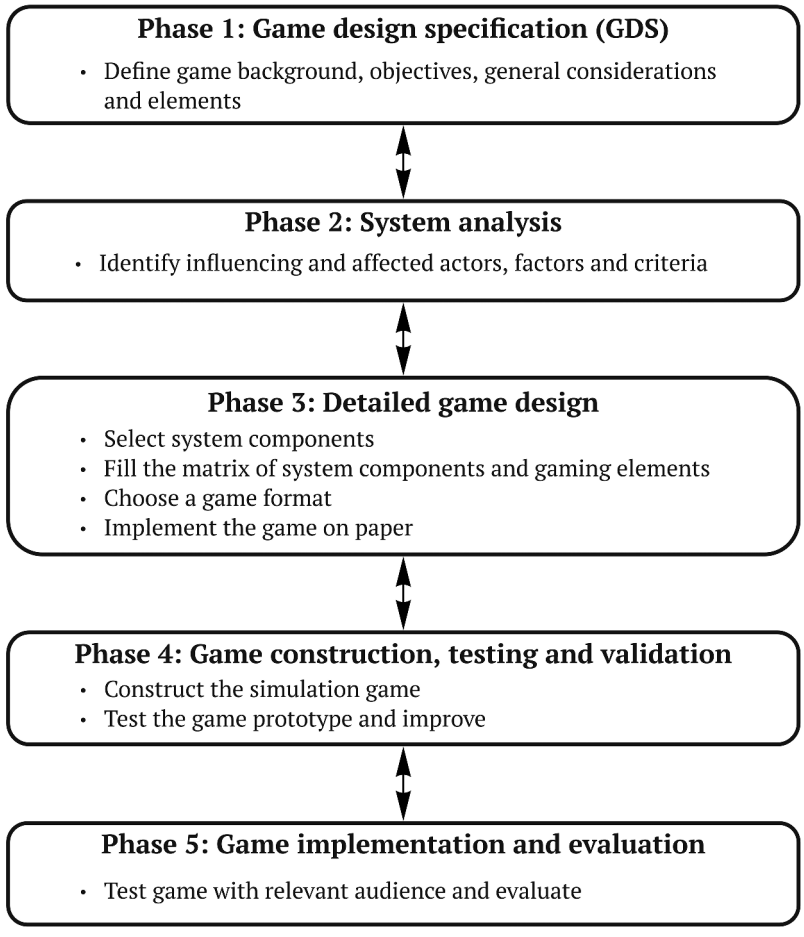

Figure 1. Phases of designing a simulation game (adapted from Mittal, Scholten and Kapelan 2022, Peters and Westelaken 2014) .

3.1.1. Phase 1: game design specifications

Phase 1 initiated with the formation of the game design specification (GDS), which was informed by the outcomes of Section 2 to construct clear learning outcomes. The GDS was approached with checklist-style questions for which the responses provided direction for the game design process while acting as criteria for validating the final game. The questions proposed in the GDS were adapted from the suggested specification checklist questions of Peters and Westelaken (2014) and covered the following themes: *background problem*, *objectives of the game*, *general considerations*, *elements of the game* and the *use of the game*. The detailed GDS is presented in Supplementary Material B.

3.1.2. Phase 2: system analysis

In Phase 2, a desk study was conducted to analyse the real-world system. Existing information within the context of the Netherlands was examined and conceptual maps were created to identify important actors and factors related to the adoption of households SuDS. This was followed by a critical selection of the most important system elements to convey through the game, considering the GDS, shown in Supplementary Material C. This stage was frequently re-iterated throughout the game design process.

3.1.3. Phase 3: detailed game design

Next, the relevant system components were mapped on a matrix against typical gaming elements that facilitate the mechanisms and dynamics of the game such as roles, rules, actions, chance, limited actions, resource scarcity, conflict etc (Peters and Westelaken 2014; Pendleton 2020). The matrix helped generate ideas and demonstrate how aspects of the system could be translated into game elements (see supplementary material D). Entertainment games such as Pandemic: Rising Tide (Z-Man Games 2023), Bärenpark (Lookout Games 2023), and Scoville (TMG, 2023) were also examined for inspiration on how to translate real-life processes into board game elements. For example, Pandemic: Rising Tide's (Z-Man Games 2023) representation of climate change as increasing sea levels inspired the inclusion of increasing volumes of rain showers and the use of physical blue cubes to represent rainfall in SuDSbury.

The final stage of Phase 3 was focused on creating *'the game on paper'*. This involved creating diagrams and visual maps to translate gaming elements into physical components for the board game. This stage was highly experimental and required several adjustments and re-iterations of all steps within Phases 2 and 3 of the game design. The basic criteria considered while doing the iterations were to balance game realism, meaning and play aspects, i.e. the game should represent the real-world while also being playable and fun as a board game and conveying the appropriate meaning as stated in the learning objectives (Harteveld 2011). Examples such as Levee Patroller (Harteveld et al. 2010) and GBGame (Juan and Chao 2015) provided insights into achieving this balance. These included balancing gameplay challenge versus achievability while maintaining realism, largely pertaining to scoring and cost scales, explained further in section 4.3. The gameplay challenge level should also convey the urgency to act in response to climate change which is discussed in section 4.4.

3.1.4. Phase 4: game construction, testing and validation

In Phase 4, the game was constructed, tested, and improved. The physical board game largely comprised printed and laminated elements, along with dice and small tokens. Informal test sessions were conducted to validate the game mechanics, realism, and gather feedback to improve various aspects such as the challenge level, complexity, fun factor, player engagement, scoring calibration and understanding of the learning outcomes. This phase was also highly iterative in which all stages of the game design were reviewed.

3.1.5. Phase 5: game implementation and evaluation

Finally, in Phase 5, the final SuDSbury game prototype was evaluated with the target audience, as described in section 3.2.

3.2. Game evaluation

The serious game was evaluated using a 'quasi-experimental' design, where participants completed a pre-game and post-game survey (see Supplementary Material E) to measure changes in their responses before and after playing the game (Hauge et al. 2015). The target audience for the game was adults (18 years of age or older) living in an urban area. The trial was conducted in the city of Delft in the Netherlands. Recruitment was done through leaflets, posters (see Supplementary Material F), and personal contacts, with respondents encouraged to invite others. During recruitment, participants were made aware that they would be testing a new educational serious game. Participation of players was voluntary and no financial incentives were provided. A total of 14 participants could be recruited, which is a typical sample size for initial results and feedback in serious game interventions (e.g. Gomes et al. 2018 used 9 participants and; Khoury et al. 2018 used 22 participants).

Following recruitment, participants were organized into three game sessions of four to six participants each based on their availability. An online poll was used to gather preferences on timeslots and participants who had the same availability were grouped together. Before the game session, participants completed an informed consent form and a pre-survey (comprising demographic data collection, knowledge, comprehension, and personal norm data collection). After the 1.5-hour game session, participants filled out a post-survey, which was identical to the pre-survey except for excluding demographic data including gameplay feedback. The study received ethical approval from the TU Delft Human Research Ethics Committee (approval no. 2335).

Demographic data such as age, housing status, education level, and familiarity with household SuDS were collected to gain insights into the results and understand how different demographic groups respond to various aspects of the game.

3.2.1. Knowledge and comprehension

The serious game aims to educate the public on knowledge gaps regarding private household SuDS and thereby influence personal norms, as described in section 2.1. To test the game's impact on knowledge acquisition, a knowledge test was developed that consisted of multiple choice questions (MCQ) and open questions (Hauge et al. 2015; Li et al. 2017; Mayer et al.

2014). Following Mayer et al. (2014)'s recommendation, participants were also asked to self-report their understanding/awareness levels related to the learning objectives.

The survey data was primarily quantitative to enable easier analysis and minimize subjective interpretation of responses (Hauge et al. 2015). The MCQs were validated with a group of nine participants to check for bias, obvious answers, confusing question forms, and ambiguous answers (Al-Faris et al. 2010). Open questions were restricted to three and were formulated such that certain keywords can indicate knowledge level, without the reliance on subjective inference of answers. Analysis of the responses was based on these keywords.

3.2.2. Personal norm stance

To assess the impact of the serious game on participants' personal norms towards household SuDS, statements on behavioural intentions and attitudes were presented. Participants used a 5-point Likert scale, ranging from 'Strongly disagree' to 'Strongly agree' to express their agreement or disagreement with these statements (Likert 1932). This captured their self-reported behavioural intention and attitudes towards adopting household SuDS.

3.2.3. Game feedback

To get a comprehensive view of the limitations of the study, it is important to collect participant feedback on the game experience. In the post-survey, statements regarding game engagement, challenge level, fun, realism, and playability were presented using a 5-point Likert scale from 'Strongly disagree' to 'Strongly agree'. Additionally, two open-ended questions were included to gather insights on what players learned from the game and suggestions for improving it.

3.2.4. Data analysis

The data analysis of the survey varied based on question type. Each MCQ was designed to feature correct and incorrect answers (correct answers are highlighted in Supplementary Material E). For each question, the 14 individual responses were grouped to find the percentage of participants who responded to each question correctly or incorrectly.

Responses to Likert scale questions were converted to numerical values ranging from 1 ('Strongly disagree') to 5 ('Strongly agree'). Then the average value for each question was calculated for the test group to find the average response of the group on the Likert scale.

Open-ended questions were analysed by identifying keywords in the responses. Responses that matched the keyword answer were considered correct, while those that did not match or stated 'I don't know' were deemed incorrect. To facilitate qualitative analysis, the keyword responses were categorized into different topics, providing a deeper understanding of how participants interpreted various aspects of the question.

4. The SuDSbury game

4.1. Game setting

SuDSbury is a 4 to 6-player table-top board game where the board, shown in Figure 2, spatially represents the hypothetical urban neighbourhood of SuDSbury featuring roads, housing, parks, shops and a school.

Players can assume one of six unique roles which provide them access to build on their associated housing blocks on the board (see supplementary material G for all role cards):

- House owner with a garden
- House owner without a garden
- House renter with a garden
- House renter without a garden
- Apartment owner
- Apartment renter

The game was designed to set the scene, game mechanisms and goals that deliver the two learning objectives as outlined in section 2.3. The introduction to the game sets the storyline that the SuDSbury neighbourhood is facing issues with pluvial flooding and has failed to secure funding to upgrade its sewers. The effect of climate change and urbanisation escalates in the game timeline in the form of increased risk of intense weather events, and loss of neighbourhood parks due to increased housing, as described in sections 4.2 and 4.4. Therefore it is up to the residents (players) to reduce pluvial flooding while also improving the town's liveability. These two objectives are represented as scoring criteria for the game where flood reduction represents the amount of overland water retention in the area, and liveability represents all environmental and social aspects that contribute towards quality of living.

4.2. Game round

The gameplay is facilitated by a facilitator to introduce the game objectives and rules and guide the players through the game. The facilitator starts the gameplay by delivering a short presentation on the game which sets the scene for the game story and covers topics such as roles, game objective, scoring, round actions, rules, and winning and losing conditions (see supplementary material H). After the presentation, players are provided with the gameplay material including role card, action cards, and item cards, which they can access throughout the game. Players begin the gameplay which consists of nine rounds that represent the years 2022 to 2030. Within every round, each player has one action per turn (see the left card of Figure 3). An action can be to implement/purchase an item for their land (if landlord approval and concerns checks allow), or to repair up to two failed items, remove an item, or pass. These actions allow the players to contribute to SuDSbury's liveability score and flood protection level. At the end of a round, a weather event takes place where a drought or flood could occur with associated consequences such as the impact on liveability score and SuDS damage. If players manage to survive the impact of the flooding/drought, they can move on to receive their annual income, pay maintenance, and proceed to the next round.

4.3. In-game items

Players can influence liveability and flood reduction scores by implementing items on the game board. There are eight items

Figure 2. Game board and associated paraphernalia of SuDSbury as arranged in the starting set-up of the game.

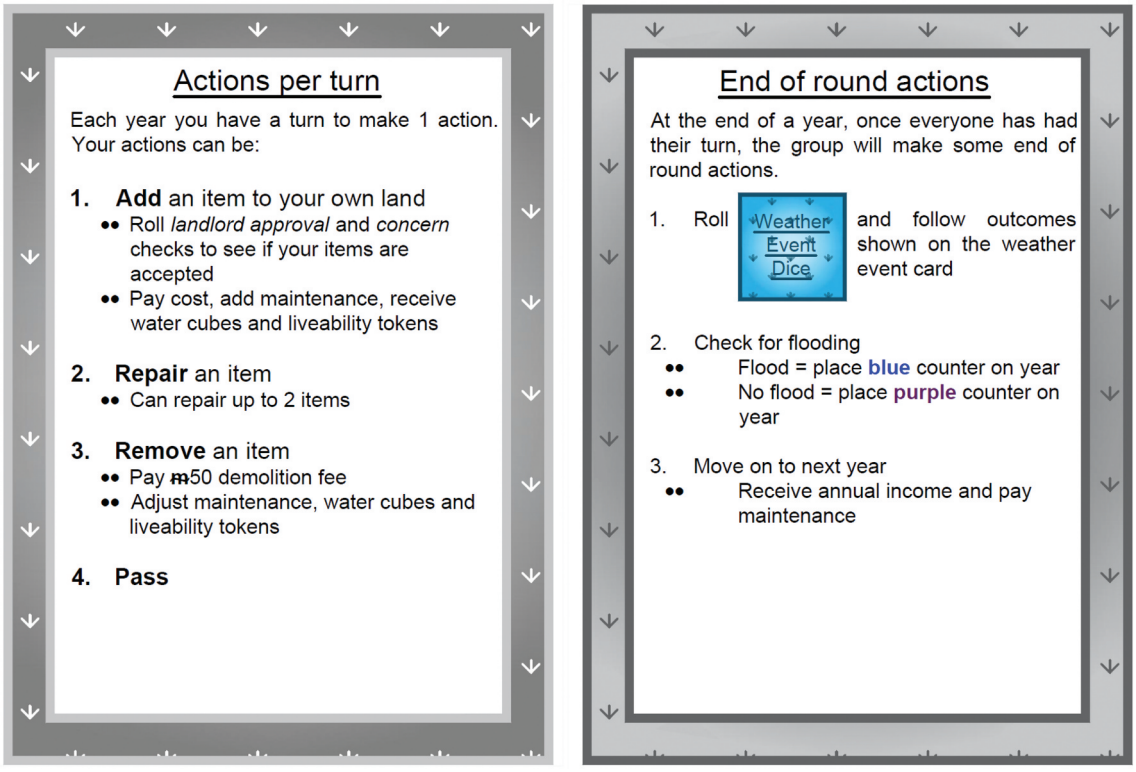

Figure 3. Cards explaining game actions and round mechanisms.

available, with one description card each (example shown in Figure 4, see supplementary material G for all other item cards). Six of these items are SuDS, and two are home improvements. The item cards provide a short description of the item along with their pros and cons, liveability scores, water storage capacity, fixed costs, and annual maintenance costs. More information on how the costs and liveability scores are calculated are provided in supplementary material I.

Access to these items depends on player roles. For instance, a house owner with no garden can only purchase and implement items that can be put on the roof or the paved area of the house, e.g. a green roof, solar panel, or a rain barrel (see supplementary material G for example). Implementing an item requires players to fulfil certain conditions. All players must roll a 'concern' dice to determine the chance of a neighbour or a member of the housing association raising concern about the proposed item. There is a 1/3 chance of receiving a 'concern' and if a concern arises, the player can answer a *'justify card'* to convince the neighbour to accept the item. Justify cards test factual trivia on pluvial flooding and drainage mechanisms to familiarise the audience with definitions and issues relating to SuDS items (see supplementary material G for examples). If answered incorrectly, implementing the SuDS is blocked. Players who rent an apartment or a house need to roll an additional dice to check if the landlord accepts their proposed items. The landlord dice has an equal chance (1/3) of blocking, accepting, or accepting the item with a financial contribution.

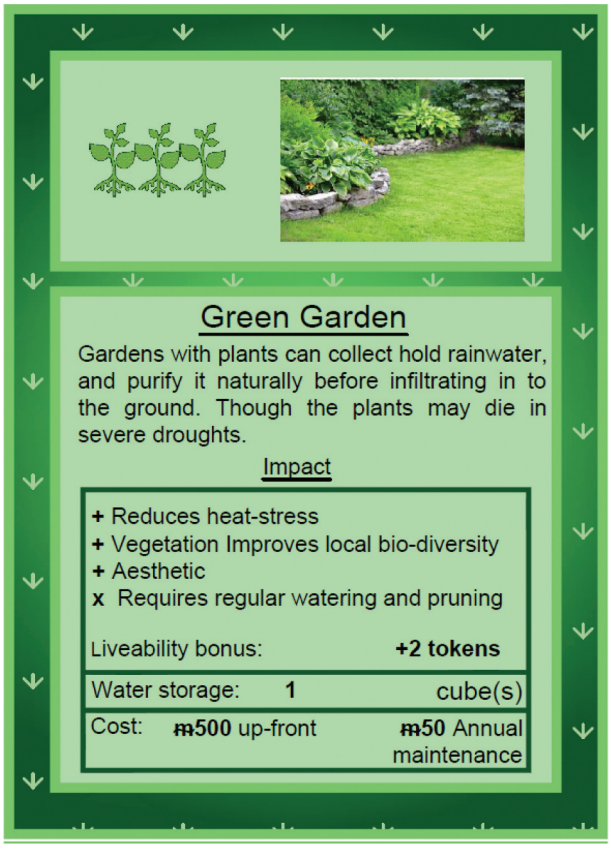

Figure 4. Example of an item card.

4.4. Weather events and flooding

The weather events that occur at the end of every round (year) follow the logic checks shown in Figure 5. Depending on the *weather dice*, rain or drought may occur. The outcomes of each weather event are detailed on a *Weather event card* (see supplementary material F). The impact of droughts is decreased *liveability*, damage to SuDS vulnerable to droughts and financial bonuses for those with solar panels. The rain events are followed by a (numerical) *rain dice* roll to determine the number of rain cubes that SuDSbury's sewers and land (represented on the *flood reduction* scale) have to handle. To represent climate change, as time progresses in the game, the chance of getting intense weather events increases as the dice faces include more severe drought and increased rain multipliers.

Flooding occurs when a rain event yields a numerical value that exceeds the sum of the sewer system capacity and the current flood reduction score. This represents a rain event that saturates all overland SuDS and the sewer capacity. The sewer capacity is set to hold a fixed number of water cubes (15) representing the typically fixed capacity of sewers due to infrequent sewer upgrades, thereby increasing the relevance of adopting SuDS.

4.5. Winning and losing conditions

In the game, the players' objectives are to reach *good* liveability scores and increase flood reduction scores such that the town can survive weather events. All players work together towards this aim by familiarizing themselves with criteria and scores of implementable items as described in section 4.3. All players are affected by the losses and gains, e.g. a flood reduces liveability score which translates to low income for all (and vice versa). As shown in Figure 5, to win the game, players must complete nine rounds, reaching the year 2030, while maintaining a liveability score greater than four and having less than three floods. If the game is won, it is a collective victory for all players, but the player who contributed the most to the overall scores is recognized as the winner. However, the game is lost if the town experiences three floods or if the liveability score drops to the minimum value of four. For further details on the game paraphernalia, see Supplementary Material F.

5. SuDSbury evaluation results

SuDSbury was tested on a participant group of 14 adults living in urban areas. The participants stated to have attained education levels between levels 2 to 7 of the European Qualifications Framework (European Union 2019). Their ages ranged between 20 to 37 years, of which 12 were between 20 and 30 years old and their housing status comprised 4 free lodgers and 10 renters.

Initial awareness of household SuDS within the participant group was captured to find that no participants have had or currently have any household SuDS, though the majority of participants knew what the most common household SuDS were, namely: garden pond, vegetated garden, green roof, permeable/porous pavement, and rain collection barrel. The results for each survey section are presented below.

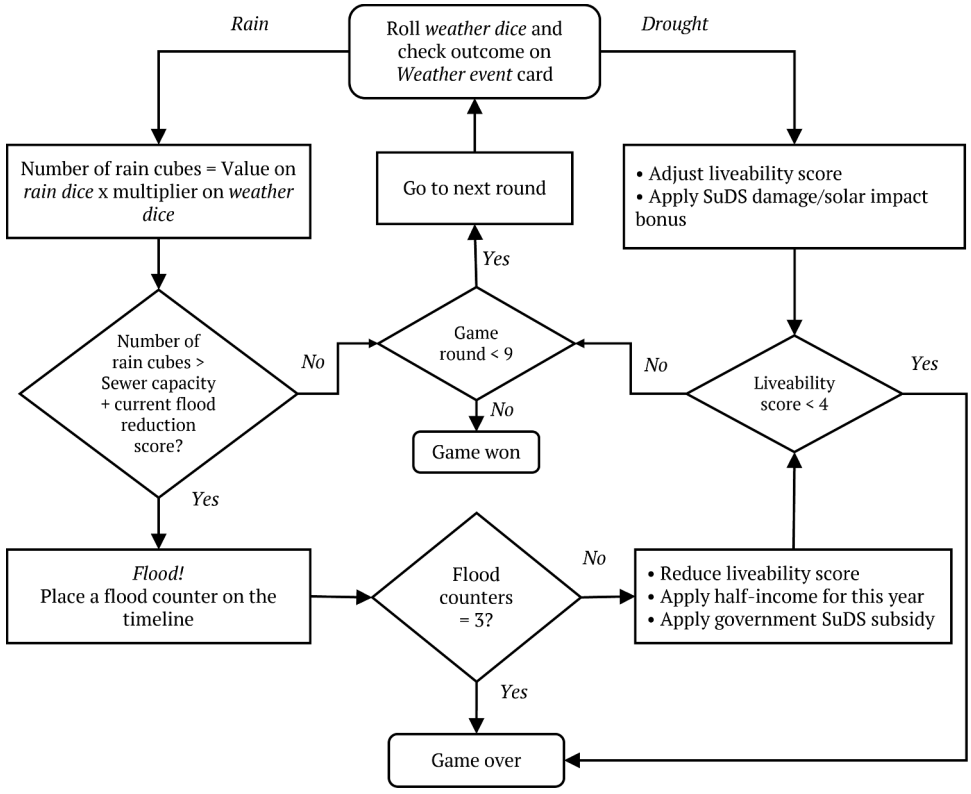

Figure 5. Flowchart of flooding, winning and losing in the SuDSbury game.

5.1. Knowledge and comprehension

The results show an increase in group average knowledge and comprehension gained after the game (see Supplementary Material J). The largest improvement was observed in the knowledge acquisition section. The knowledge acquisition section of the survey contained three open questions. Not only were more correct answers collected post-game, but of those correct responses, the post-game answers were generally richer and considered more aspects than mentioned pre-game, although they did not capture full descriptive sentences. Every question or statement indicated a group average increase except one comprehension question (see C.2 *How does infiltration of rainwater affect pluvial flooding?* in Figure 6) that resulted in a decrease (22%) in correct answers after the game.

The results of the self-reported learning section (Figure 7) show that the pre-game awareness level of topics (statements S1-S5) related to learning the urgency to act in the context of urbanisation and climate change (LO1.1) are significantly higher than initial awareness levels on topics relating to household SuDS (LO1.2; inferred from statements S6-S9). Subsequently, the improvement in awareness level of LO1.2 topics after the game is significantly higher than for LO1.1 topics.

5.2. Personal norm attitudes to SuDS

The results of participants' personal norm stances on SuDS adoption are shown in Figure 8. All statements that pertain to acceptance of household SuDS observe an increase in

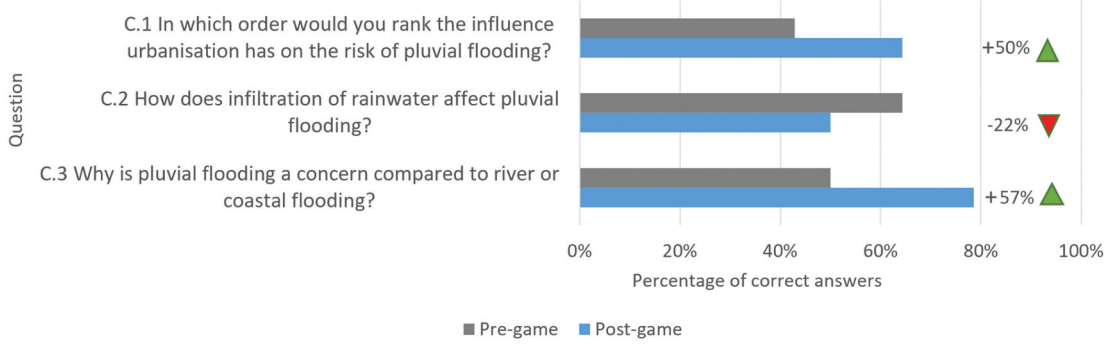

Figure 6. And post-game percentage of correct answers to questions C.1, C.2 and C.3 (the percentages on the right of the chart indicate the % change in the correct responses).

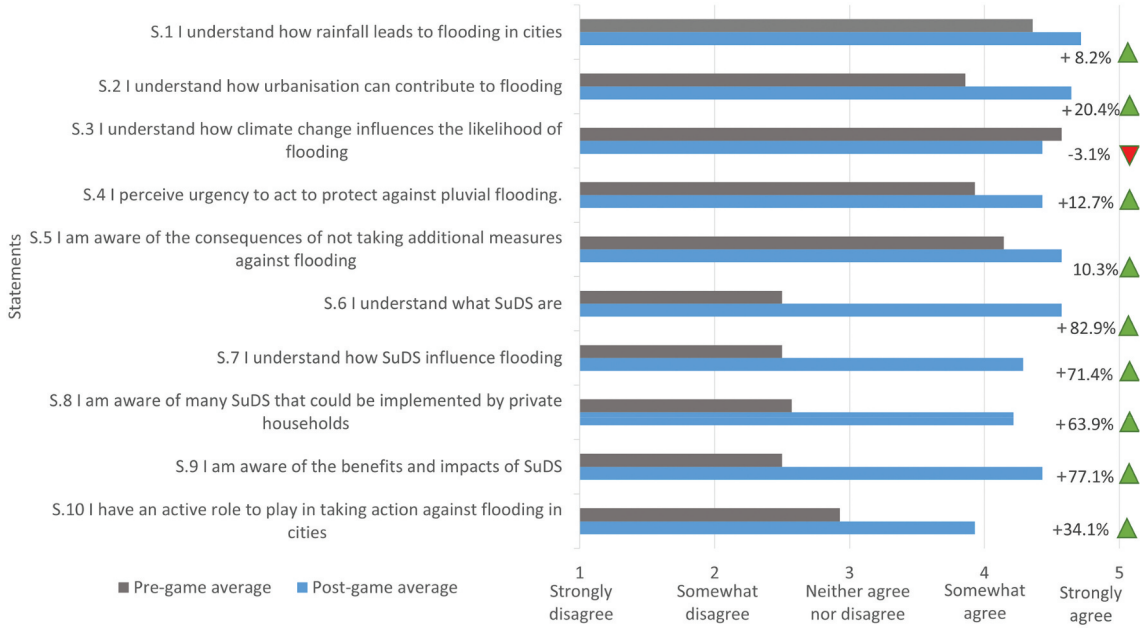

Figure 7. And post-game average score of 14 participants on self-reported knowledge and comprehension levels of household SuDS (the percentages on the right of the chart indicate % change in the average response).

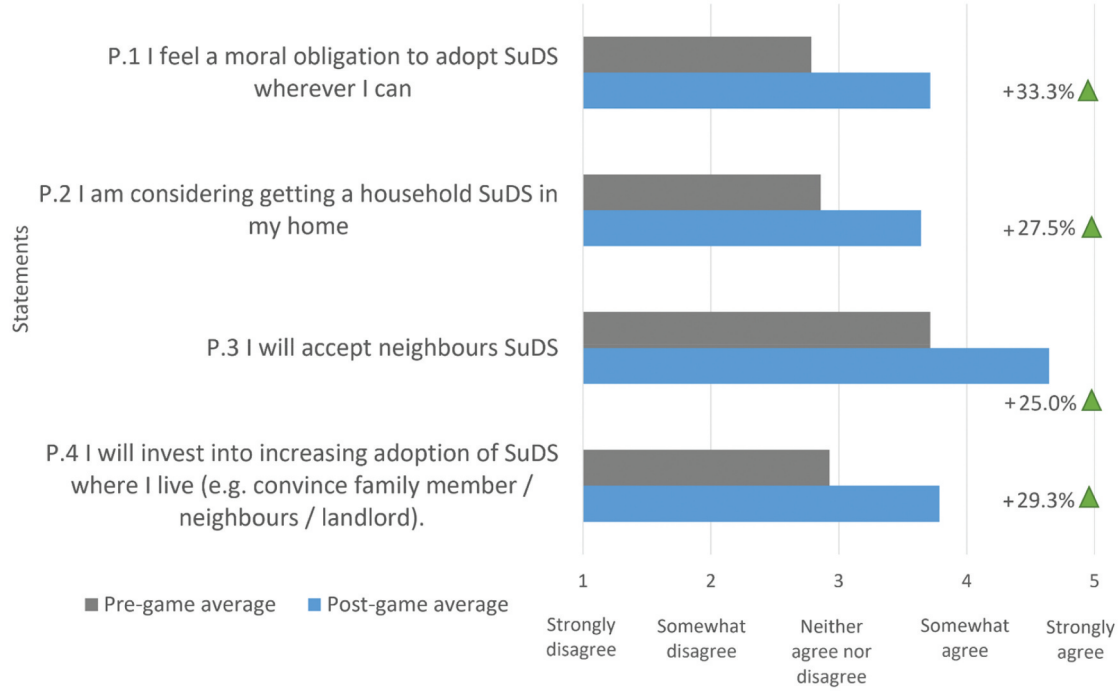

Figure 8. Pre and post-game average score of 14 participants on personal norm attitudes towards household SuDS (the percentages on the right of the chart indicate % change in the average response).

acceptance, with a 25% or more increase in the average response post-game compared to the pre-game responses.

5.3. Gameplay experience

Following the game, participants provided feedback on the gameplay experience on a scale of agreement shown in Figure 9. Overall, the groups strongly agreed that the game was fun, engaging, and the rules were clear. The group somewhat agreed that the game was easy to follow, and they learnt a lot in the game. The group somewhat agreed that the game was realistic and neither agreed nor disagreed that the game was easy to win.

Participants further responded to open questions (full responses are presented in Supplementary Material J). On the topic of entertainment, responses contained statements such

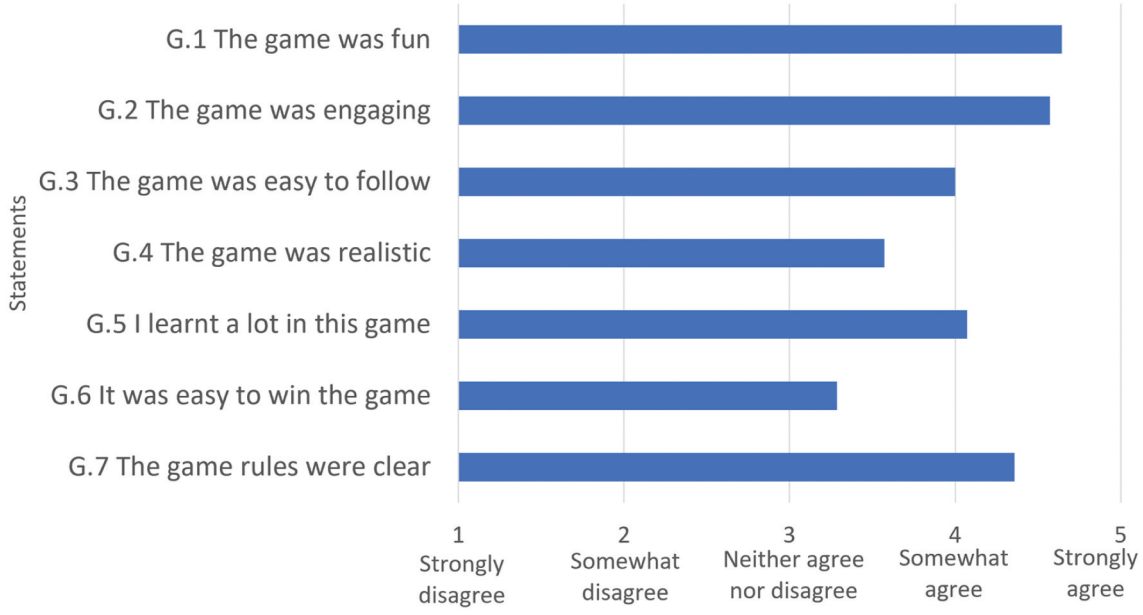

Figure 9. Post-game average rating of 14 participants for gameplay experience.

as: '*it is a nice game!*' and *'it was engaging'*. On the topic of game realism, participants suggested improvements such as: *'Adjust the sewer capacity', 'Make it a trade-off between water absorption and money'* and *'Try to be more realistic. Not all people are available to implement water SUDS'*. On describing their learnings from the game, participants responded with statements such as: '*I have learned about SuDS*' and '*I learned a lot*'. Three participants mentioned that they were surprised to learn that specific household SuDS, or SuDS in general, can impact flooding. Three participants mentioned they were surprised to learn that 'we' (as the general public) or individual households could impact pluvial flood risk. On the topic of the challenge or difficulty level of the game, one participant suggested '*Make it a bit harder*'. On the clarity of game rules and ability to follow the game, responses ranged from statements such as: '*Game rules could be more specified*' to '*It was very clear for me*'.

6. Discussion, limitations and recommendations

6.1. Game performance

The game design specification emphasized balancing play, meaning and reality. Feedback on gameplay experience highlighted the game's success in aspects of play such as fun, engagement and entertainment. While feedback on game meaning and reality was positive, they were not as highly regarded as the play aspect.

The game's meaning is its success in educating. While quantitative knowledge and comprehension results show the game was successful in educating, gameplay feedback shows there is room for improvement as the group only *somewhat agreed* that they learnt a lot in the game. The study identified knowledge acquisition as the area with the highest potential for improvement. Nevertheless, improvement in knowledge acquisition was not equal between the two learning objectives. Notably, there was a disparity in initial awareness levels between the two learning objectives, with higher awareness levels on the *urgency to adopt SuDS in the context of urbanisation and climate change* (LO1.1) compared to *household SuDS functions and requirements* (LO1.2).

To enhance the educational impact of the game, it should be re-designed to acknowledge existing awareness levels and target higher levels of the Bloom et al. (1956) taxonomy such as 'application' and 'analysis'. More emphasis can be placed on the technical aspects of SuDS. For example, players can be challenged to come up with a stormwater plan that can store a certain amount of rainfall through the implementation of SuDS and test its resilience against different rainfall events. Additional player roles such as the municipality, wastewater utility, or other public authorities who often have a significant influence on the uptake of household SuDS (through the provision of subsidies or otherwise) can also be introduced. By stepping into the shoes of different stakeholders, players can get a broader understanding of their perspectives and interdependencies.

The game was less successful in impacting participant comprehension level than knowledge acquisition. Comprehension is a more evolved thinking process, therefore requires understanding and interpretation of concepts. Comprehension question C.2: *How does infiltration of rainwater affect pluvial flooding?* scored particularly low after the game. Upon reflection, the game inaccurately represented infiltration processes by equating it to retention within the game mechanics. This highlights the need for accurate game realism and showcases the drawback of oversimplification in serious games. To improve realism, distinction in the game mechanics should be made for SuDS that infiltrate, retain, attenuate, convey, filter and collect as a resource. Introducing a 3D version of the board game or an accompanying simulation system can provide players with

a better understanding of how stormwater travels away from the visible urban subsurface which is difficult to imagine in a 2D game.

The study supports the causal dependencies posited by the SSBC model (presented in section 2.3), showing that the educational game intervention can influence personal norm stance towards household SuDS adoption, albeit through mediation and moderation by other variables (Steg and De Groot 2010). The serious game influenced the formation of goal intentions and demonstrated potential for deliberative behaviour change. Further work would be to assess the impact of the game on long-term awareness levels and personal norms. Additionally, data on the moderating and mediating variables can be collected to ascertain the contribution of awareness-raising as compared to the effects of other variables on the formation of personal norms.

6.2. Game design

The game design method followed an iterative framework presented by Peters and Westelaken (2014). Upon reflection, the process was more circular and iterative than initially expected. Certain tasks or aspects could be skipped or only briefly considered in the early iterations. For example, in Phase 1, addressing elements of the GDS could not be addressed without required prior consideration of the selection of system components, which according to the framework, should follow the GDS in Phase 3. This applied to specifications outlining aspects of reality that would feature in the game, and who would be the main actors. In practice, it was manageable to address sections of the GDS-related system components iteratively. However, the framework should clarify that these decisions do not have to follow a strictly linear process to avoid getting stuck or making premature, ill-considered decisions.

Another example is populating a matrix of system components and gaming elements in Phase 3. Additional input was sought from Pendleton (2020) as it provided a wide range of possibilities on how a game element could represent a system component. However, this process can become time-consuming if a decision or shortlisting of game formats is not made at an early stage. For example, considering the game format and structure while brainstorming for rules, actions and scoring can be helpful.

The matrix task, in particular, was a highly creative process that required brainstorming sessions and research into existing game approaches. It is recommended to incorporate creative stimulating exercises, such as mind-mapping, visual diagrams, and team collaboration or focus groups during Phase 3 of the game design framework. Lastly, certain aspects of the design specifications checklist from Peters and Westelaken (2014) that pertain to client deliverables, ownership, and responsibility details were omitted as they were not relevant to a serious game developed for research purposes.

6.3. Testing procedure

The effectiveness of the SuDSbury game was tested on a small and limited demographic sample of 14 participants, mostly between the ages of 20 and 30 years, who were renters and free lodger residents. Due to these restrictions, it was not possible to analyse responses across different demographic groups, nor to have all six player roles represented in the testing group. To draw valid conclusions, a larger and more representative sample including diverse demographic groups with varying gender, ages, education, and home ownership is needed (Meyer 2015; Patel, Modi, and Paul 2017). The necessary sample size can be determined based on the observed size of the effect.

The survey design could also be improved by using larger text entry boxes to generate richer responses (Reja et al. 2003). It is likely that engagement in the process diminished at the post-survey stage, leading to reduced effort in the post-survey responses. A more interactive debriefing and group discussion could be deployed as an alternative post-game evaluation method to gather more meaningful and detailed feedback (Grund and Schelkle 2020). Furthermore, low improvement in comprehension learning could also be attributed to the survey design. The framing of three MCQs in the comprehension section could be improved to avoid ambiguity of interpretation. For instance, an answer to question C.2 that was considered incorrect could be true in certain circumstances that were not explained in the question. Scenario-based explanation questions could be more suitable in such cases. Additionally, limiting the game sessions to 1.5 hours could also have been a limiting factor for participant comprehension growth. Further research could explore if comprehension improves with longer, or multiple game sessions, where the player is exposed to more scenarios and can experiment and reflect on more strategies.

To strengthen the argument for serious gaming as an intervention in public education of household SuDS, a more rigorous randomised controlled trial (RCT) could be conducted. This RCT could evaluate the game's performance, against a control group of the same target audience, educated on the same topics through an alternative education method such as lecturing, videos, demonstrations, or public awareness publications (Hauge et al. 2015; Mayer et al. 2014; Squire et al. 2004). This comparative analysis can provide valuable insights for public engagement strategies on SuDS issues and further establish serious gaming as an effective medium for raising public awareness.

Finally, it is important to note that the test group was aware that the game was educational, and some participants had a personal relationship with the researcher who facilitated the game session. This introduces potential experimental bias as participants may be influenced to meet the researcher's expectations, which could impact the accuracy and quality of the results, favouring increased learning outcomes. To minimise this bias, 'blind' protocols should be considered (Holman et al. 2015). These protocols can involve recruiting participants without personal relationships with the researcher, withholding the game's purpose from the participants, and using an independent facilitator who is unaware of the study's goals.

6.4. Game viability and accessibility

While SuDSbury can be played by 4 to 6 players, it can be reproduced and translated to make it available to a wider audience. Municipalities, community organizers and educators

who interact with urban residents are encouraged to use the game in their engagement activities. For example, the game can be used during planning or engagement sessions related to urban water infrastructure projects at the neighbourhood level. By providing a safe space to better understand the urban drainage concepts and improve knowledge about households and other SuDS, the game can effectively engage urban residents and help obtain their support/buy-in for the proposed scheme(s) along these lines.

We expect that the general public may exhibit initial hesitancy towards engaging in a game that necessitates a substantial time commitment. As a result, we propose targeting specific cohorts such as community frontrunners, sustainability-minded individuals with an inclination towards urban planning and environmental issues, as well as board-game enthusiasts. By engaging these particular groups, we can harness their enthusiasm and support to generate momentum for serious game intervention.

To make SuDSbury accessible to practitioners, future work should focus on creating a validated and more polished version of the game. The game can be made available as a stand-alone board game that does not need a facilitator. This would involve preparing a comprehensive game manual that introduced the storyline and provides detailed game rules. Game materials that can be printed such as player cards, item cards, game money, and game board can be made available online for download. Alongside these resources, a list of paraphernalia required for gameplay can be provided, allowing players to gather them independently. A dedicated website can be created to make the game available as an open-source education resource and can be further marketed on platforms, e.g. Game4Sustainability (Centre for Systems Solution 2018) that curate serious games across different sustainable development goals. Lastly, there is potential to develop a digital version of the game, although this would require substantial resources to ensure a high-quality user experience and careful consideration of the advantages and disadvantages compared to the physical board game format.

7. Conclusion

This paper presents 'SuDSbury', a serious game designed to educate urban residents about household SuDS to overcome the lack of knowledge and awareness of SuDS as a barrier to their adoption on private land. The board game represents the impact of household SuDS on a neighbourhood scale. A group of 14 participants tested the game and their change in knowledge acquisition, comprehension, and personal norm stance were evaluated using a before-and-after survey. We found that:

- SuDSbury can educate citizens about household SuDS, with the largest improvement observed in knowledge acquisition and comprehension of what household SuDS are and their function.
- SuDSbury influenced personal norm stances to be more agreeable with household SuDS adoption by raising awareness of SuDS and their role in flood risk reduction.
- SuDSbury appealed to the players. Further improvements could emphasise the meaning and realism of the serious game by capturing ground infiltration more realistically for better comprehension of urban drainage concepts.
- Prior understanding of public awareness and knowledge concerning specific learning objectives would allow to better target the game to individual or group-level learning needs, increasing its impact.
- The game design process was far more circular and iterative than expressed by Peters and Westelaken (2014).
- The pre-/post-test evaluation design was easy to administer and able to establish the game effects. It should be refined to reduce potential response biases and improve the measurement of knowledge acquisition.

The evaluation of the game was based on a small test group with limited demographic diversity in age and housing status. A more extensive study should include more participants that represent the wider population. The study was also limited in time scale and diversity of possible serious game uses during public engagement interventions. Further research could monitor participants over a longer time period to evaluate the long-term impact on learning and behavioural change and explore the impact of multiple play sessions of SuDSbury. The game can be further modified to suit the specific educational/awareness needs of stakeholders other than the general public. Another potential upgrade to the game could be to cover how SuDS can be used to deal with droughts in addition to floods. It would also be valuable to explore how SuDSbury is used as part of a larger engagement or decision support intervention and compare the outcomes across different target audiences, the intended purpose of using the game and playing the game at different stages of the intervention. To enhance the quality of results, a post-game debriefing and discussion session could capture a richer response. A game validated in an RCT could support the evidence for serious games' effectiveness as a public education method about SuDS.

Notes

1. Pluvial (rainfall) flooding is caused when the runoff resulting from intense rainfall exceeds the capacity of the underground sewer network. It should not be confused with the fluvial (river) flooding, which occurs when rivers or streams overflow their banks as a result of heavy rainfall or snowmelt (Falconer et al. 2009).
2. Also referred to as LID (Low impact development), BMP (Best management practices), WSUD (Water sensitive urban design), NBS (Nature-based solutions), GI (Green infrastructure) or BGI (Blue-green infrastructure) (see Fletcher et al. 2015 for a full taxonomy)

Acknowledgements

We are grateful to Alexander Garzón, Diana Callejas Moncaleano, Dr. Job van der Werf, and Roberto Bentivoglio from the faculty of Civil Engineering and Geosciences at TU Delft for play-testing the game prototype and providing valuable feedback during early stages of game development. We also thank all anonymous participants who participated in the gaming sessions for their valuable time and express our gratitude to two anonymous reviewers for their feedback that has significantly improved the quality of the paper. Lastly, the second author acknowledges funding from the European Union's Horizon 2020 'WATERAGRI: Water retention and nutrient recycling in soils and streams for improved agricultural production' research and innovation programme under Grant Agreement No. 858375.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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