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Serious gaming to support the adoption of sustainable drainage solutions

MSc Thesis

TU Delft

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A serious game to educate citizens about private household SuDS

By

J. Nguyen

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Serious gaming to support the adoption of sustainable drainage solutions

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Serious gaming to support the adoption of sustainable drainage solutions

There is an urgent need for urban environments to be more flood resilient. The public can participate in addressing this by adopting household sustainable drainage solutions (SuDS). However, their lack of knowledge and awareness is a barrier. This paper presents an educational serious game to overcome this barrier and explores whether it can educate citizens about private household SuDS (and to what degree). A serious game named Sudsbury is designed to educate the public on household SuDS and the urgency to adopt them in the context of climate change and urbanisation. A study of 14 urban inhabitants participated in three game sessions evaluated with pre and post-game surveys. The study found that Sudsbury is a fun and engaging public intervention method successful in educating and impacting personal norm attitudes, with the potential to create growth in support and adoption of household SuD. Sudsbury was most successful in improving knowledge acquisition of household SuDS but found comprehension of concepts was limited by deficiencies in the game realism.

1.0 Introduction

Pluvial flooding is an increasingly significant cause of devastation to urban settlements in economic losses and disruption to life (Jha 2012). This issue is compounded by growing 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). Alongside that, drainage demands are growing due to climate change. Heavy precipitation is projected to affect over 80% of global regions (MassonDelmotte 2021), and extreme and intense storms, are expected to occur more frequently, particularly in regions such as northwest Europe (Jan Kyselý 2011).

Traditional approaches to urban drainage focus primarily on implementing a centralised system of sewers to drain stormwater. This is a mono-functional approach whose vulnerabilities are exposed by increasingly frequent pluvial flood events and degradation of local water quality (Nguyen, et al. 2019). Towards the end of the 20th century, many urbanising countries developed strategies to tackle the aforementioned urban drainage issues that aim to implement integrated, sustainable urban water management that mimics natural drainage processes to ensure water supply, quality and flood resilience, while incorporating wider environmental and social values such as biodiversity and amenity (Nguyen, et al. 2019, susdrain n.d.). This approach is termed SuDS.

Despite decades of background, research and examples of SuDS, the approach has failed to be integrated into urban water management practice in a widespread manner beyond ad-hoc, novel implementations (R. R. Brown 2009). There are numerous studies from areas such as the USA, Europe, Australia, New Zealand and China, concerning the barriers SuDS face in being adopted reaching a wide range of areas from biophysical to socio-political aspects (O'Donnell 2017, Roy, et al. 2008, L. C. Li 2020, White 2005, Cettner 2012, Winz 2014, Wihlborg 2019, Brown and Farrelly 2008). One frequently mentioned barrier is public lack of knowledge and awareness of SuDS (O'Donnell 2017, L. C. Li 2020, Winz 2014, Wihlborg 2019, Nguyen, et al. 2019). A recommendation to overcome this is to educate the public on SuDS with strategies that aim to engage and raise awareness of SuDS (L. C. Li 2020, Thorne 2018).

The role of the general public in SuDS adoption can take many forms. The most obvious is that citizens are the end-user, beneficiaries, and consumers of SuDS (Jeffrey and Seaton 2004). The public are receivers of the service that is flood protection, plus any other multi-function that SuDS may provide. Restemeyer and Boogaard (2020) postulate that in the context of climate adaptation, efforts to transition will depend on "ordinary" citizens amongst other local groups. This relates to the fact that the urban land cover can typically comprise 60% housing, therefore inhabitants have significant spatial opportunity to implement household-scale SuDS that can contribute towards urban climate adaption. Therefore, in this paper, we focus on educating the general public about the urgency to adopt household SuDS.

To gain public support and participation for household SuDS, the public should be engaged and educated however, recommended public intervention methods are largely unspecified (O'Donnell 2017, Thorne 2018, Nguyen, et al. 2019). Additionally, Roy et al. (2008) recognises that despite the availability of informational publications and public demonstrations, understanding of SuDS has failed to penetrate public consciousness. Therefore, there is a need to establish and test an intervention method that is engaging, educational and effective in impacting public participation with SuDS. A serious game is a medium where people can be engaged in an immersive manner to teach, develop, or practise a skill (Lukosch 2018). The term *serious game* is defined in the context of educational gaming by David Michael (2006) as, *"a game in which education (in its various forms) is the primary goal, rather than entertainment."*. The appeal that serious games have over other forms of education such as traditional teaching or reading, is that serious games are effective in presenting a complex system that is digestible for learning (Lukosch 2018). In the field of

water, gaming applications are popular, however, there is the opportunity for the development of a serious game applying specifically to SuDS issues (Savic, Morley and Khoury 2016, Aubert 2018).

In this paper, we address the research question: *Can a serious game educate citizens about private household SuDS (and to what degree)?* We present the design and evaluation of a serious game, Sudsbury, aimed at educating the public on household SuDS and the urgency to adopt them in the context of climate change and urbanisation. The serious game was tested for its educational performance and subsequently, its impact on support for SuDS by measuring awareness and personal norm attitudes towards household SuDS adoption in a pre and post-game survey.

In Chapter 2, we explore the background and application of serious games alongside establishing targeted learning objectives under theoretical educational and behavioural change bases. In Chapter 3, the methodology for the serious game design approach and its evaluation are outlined. In Chapter 4 the game, Sudsbury and its specification are described. Following that in Chapter 5, the results of the game evaluation are presented with discussion and limitations considered in Chapter 6.

2.0 Targeting the serious game to effectively address public education of household SuDS

This chapter aims to understand how public awareness level of household SuDS can be addressed effectively through an educational serious game.

2.1 Public education to tackle SuDS adoption

Public lack of awareness and understanding of what SuDS is and its functions has been recognised in several literature studies as a barrier to SuDS adoption (O'Donnell 2017, Roy, et al. 2008, L. C. Li 2020, Nguyen, et al. 2019, Krijnen 2020). For example, residents in Amsterdam observe knowledge gaps between understanding the urgency to be flood resilient and are unaware of the solutions that can be implemented as inhabitants (Krijnen 2020). Low public awareness levels and indifferent attitudes to urban drainage issues can further result in impeded participation in local water management initiatives (Roy, et al. 2008). This contextualises the need to educate the public.

The role of public education is essential for promoting sustainable development and resilience as it can promote value for the local environment (Restemeyer and Boogaard 2020).

UK water utility company Thames Water demonstrate community engagement by delivering an educational outreach programme, *Thames 21* that aims to develop community value for riverine systems and raise awareness of the issues it faces. The goal of *Thames 21* is to empower the public to enable them to become future guardians of the waterways (Thames 21 2022). This is an example of how educational community interventions can influence public values and ultimately pro-environmental behaviours.

Public lack of knowledge of SuDS issues and functions is of particular concern given a large portion of urban land cover is owned and managed by private inhabitants. Bassone-Quashie's (2021) study emphasises that to tackle urban flooding, *"everyone has to do their part"*, relating to the fact that all landowners (including private inhabitants) must participate. Therefore, efforts to equip the public with knowledge to participate is imperative.

Bassone-Quashie (2021) finds that the public is not activated to consider household SuDS because they are not aware of the issues SuDS address and how imminent they are, pertaining to the escalation of urban pluvial flood risk due to climate change and urbanisation. This lack of knowledge creates a lack of engagement and urgency to act (Bassone-Quashie 2021). Therefore, the knowledge gaps that should be addressed are SuDS functions to reduce pluvial flooding and damage, conveyed in the context of growing urbanisation and the threat of more extreme weather due to climate change. It should be emphasised that more extreme storms and longer droughts will make SuDS issues more vulnerable in the imminent future, therefore there is an urgency to be climate adaptive. This should be the main message of the serious game.

To supplement that, information should also be conveyed about the applications of household SuDS as this is a knowledge gap that could hinder confidence to adopt household SuDS. Buurman, et al. (2021) recognise that the public may be more understanding of the value of larger, neighbourhood-scale SuDS, however, there is poorer understanding of the impacts of smaller-scale, private household SuDS. Krijnen (2020) finds that public inhabitants are not aware of the range of household SuDS that can be implemented. Therefore, household SuDS that are realistically accessible to urban inhabitants should be selected and their functions outlined. This knowledge should support the public in decision-making processes to determine which SuDS is the *'best fit'* for their situation (Krijnen 2020).

Another relevant household SuDS criteria to convey are the distinction between construction and maintenance costs as Wihlborg (2019) identifies a knowledge gap in

maintenance requirements of household SuDS as a barrier. In addition, the maintenance requirements in terms of time and resources for the owners should also be included.

It is also recommended that the multi-functional benefits of SuDS are promoted, such as improvements to the environment, biodiversity and water resources. Promoting benefits is a key communication strategy because SuDS benefits can encourage public receptivity (Krijnen 2020, Thorne 2018, Williams, et al. 2019). For example, the study of Williams, et al. (2019) found that residents in proximity to SuDS on housing estates highly valued natural-looking SuDS that provided green space which contributed to acceptance levels and willingness to pay for SuDS maintenance.

2.2 Serious games

The application of serious games or gamification in the field of water is not new. Aubert (2018), conducted a review of serious games in the water field that range from low to high tech, and from simplified to highly complex concepts. Serious games have been developed for purposes such as raising awareness of water-related issues (e.g. Stop disasters! [Pereira, Prada and Paiva 2014]) to developing decision-making skills (e.g. Irrigania [Ewen 2016]) and their target audience spans from school children (e.g. ReNUWIt Water/City Design Challenge [ReNUWIt 2022]), to professionals (e.g. The Waas Pilot [Valkering, et al. 2013]). A serious game designed to raise public awareness around the societal issues of flooding is FloodSim. The study of FloodSim conveyed through the medium of a simulation serious game with strong pedagogical approaches, the general public was engaged to become more aware of the societal issues faced in the real-world complex system surrounding flood policy (Rebolledo-Mende, et al. 2009). Despite that, no serious game has been identified yet to tackle public education of household SuDS.

Many SuDS have high interaction with other urban features and processes such as social amenity, aesthetics, and economics (Esmail and Suleiman 2020). As a consequence, multiple actors will have a stake in the implementations. These interactions illustrate a complex system in which the single implementation of a SuDS can affect many other local processes at varying degrees, reflected in the definition of a complex system, where *"there are multiple interactions between many different elements of the system"* (Lukosch 2018). Complex systems have a background in being conveyed through simulation games which is a genre of gaming described by Lukosch (2018) as *" experimental, rule-based, interactive environments, where players learn by taking actions and by experiencing their effects through feedback mechanisms*

that are deliberately built into and around the game". Simulation games can represent a real-life complex system with pre-determined levels of fidelity in which a player can interact with components of the system as an actor to observe feedbacks, learn, correct, and solve problems (Plass, Homer and Kinzer 2015). This facilitates freedom for active experimentation or '*learning by doing'* where cognitive and social engagement takes place to develop knowledge and understanding of consequences within the system (Lukosch 2018, Plass, Homer and Kinzer 2015). This opportunity for independent experimentation is recognised to teach problem-solving skills by practising scenario-based decision-making (Kirschner and Hendrick 2020). In addition, a game setting can be an encouraging environment for *graceful failure* as Plass, Homer and Kinzer (2015) terms it, which is the ability of the player to learn from failing, without the social stigma. It allows full freedom for self-regulated learning through experimentation and assessing the outcomes to stimulate decision-making skills. Juan and Chao (2015) express specifically for table-top simulation games that they can be an accessible and environmentally friendly way to convey a complex system in a safe, controlled, and often cheaper way than allowing the player to interact in the real-life setting (Lukosch 2018, Cheng and Annetta 2012).

In addition, a defining feature of a serious games, in general, are incentive systems which stimulate engagement and motivation in the player (Plass, Homer and Kinzer 2015). As a result of being entertained, a player experiences a positive mood which further makes the player more receptive to the messages of the game (Juan and Chao 2015). To support this, the study of Zhonggen (2019) found improved academic performances through game-based learning when compared to a traditional classroom teaching method.

2.3 Psychological and pedagogical approach

To ensure the educational game intervention is appropriately targeted to address specific behavioural and pedagogical processes, behavioural change and educational models are assessed to find pathways in which an educational intervention can influence an individual's support for SuDS.

The field of environmental psychology is of specific relevance as it tackles issues of human relation to the natural and built environment (Gifford 2014). A conceptualisation of pro-environmental behavioural change can be described by the *stage model of self-regulated behavioural change* (SSBC) which draws upon behavioural theories such as *the theory of planned behaviour (TPB)* and the *norm activation model (NAM)* to form the comprehensive

framework that describes behavioural change applied to environmental psychology shown in Figure 1 (Keller, Eisen and Hanss 2019). The SSBC is broken down into stages that influence an individual's process in exhibiting a new behaviour; the predecision stage, preaction stage, action stage and finally, the postaction stage.

Between the stages, predecision and preaction in the SSBC, a distinction between the *goal intention* and the *behavioural intention* is made. Goal intention is a pre-requisite to behavioural intention where the individual forms a stance on a subject by weighing up desirability and feasibility of competing goals and therefore determines a perspective on how they feel about a subject and therefore, a pre-requisite to deciding how they intend to behave in response. Goal intention can have the structure of '*I intend to reach this goal'* or *'I intend to support X'* (Bamberg 2013).

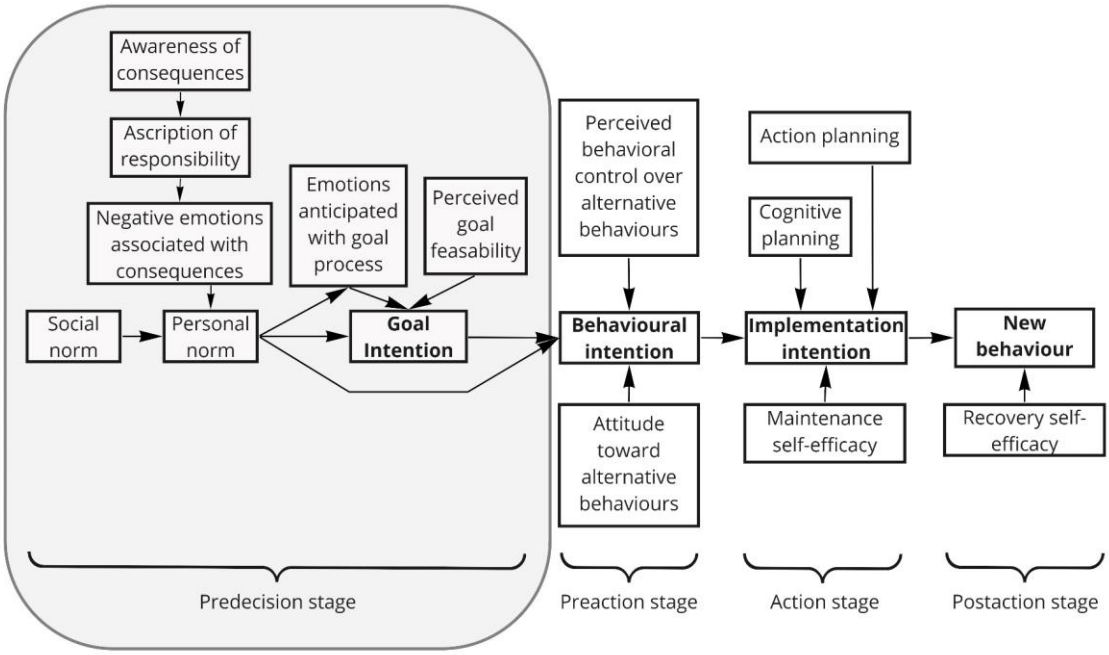

Figure 1- Stage model of self-regulated behavioural change (Keller, Eisen and Hanss 2019)

A contributing factor that informs goal intention is the personal norm. A person's personal norm refers to an individual's formation of personally important moral standards that they feel obliged to be aligned with (Onwezen, Antonides and Bartels 2013). The factors that inform personal norm are derived from the NAM which comprises *awareness of consequences, ascription of responsibility* and *negative emotions associated with consequences,* alongside the influence of perceived *social norms*. This can be described as a person's moral standards being shaped when the consequences of behaviours (good or bad) are understood, and the person

accepts their personal responsibility to *do the right thing* and behave in a less harmful way to avert feelings of guilt and shame for causing harm (de Groot, Bondy and Schuitema 2021).

Section 2.1 identifies household SuDS knowledge gaps that under the NAM contribute to the *awareness of consequences* factor. Nordlund and Garvill (2003) describe awareness of environmental issues as an important antecedent of pro-environmental behaviour as it activates feelings of moral obligation i.e. personal norm. The connection can be described as when an individual has no awareness of the issues and consequences of various urban drainage measures, the individual will not be capable of forming moral standards on the subject. However, an intervention that informs the individual of the consequences of drainage on pluvial flood risk will equip the individual with knowledge to inform a personal norm standpoint, therefore motivating goal intentions within the pre-decision stage of the SSBC. This describes the psychological basis for the educational intervention in which the testing variable is to influence personal norm through raising awareness of the consequences of household SuDS within the pre-decision stage of the SSBC.

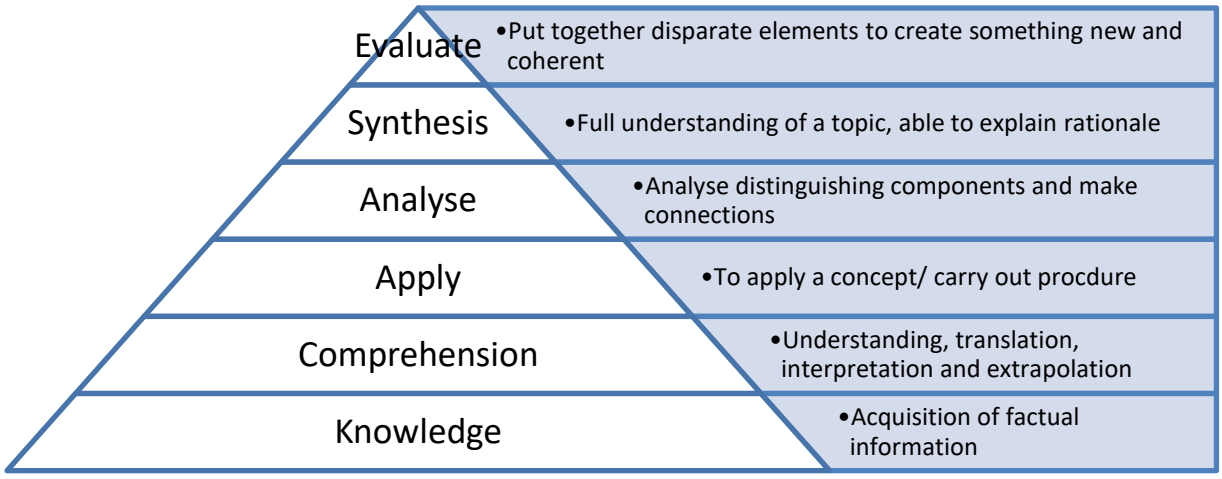

Figure 2 - Bloom's taxonomy of educational objectives (Buchanan, Wolanczyk and Zinghini 2011, Krathwohl Autumn 2002, Vol 41)

The pedagogical approach to raising awareness considers Bloom's (1968) taxonomy of educational objectives which sets a hierarchical framework of six cognitive domains of thinking shown in Figure 2 (Buchanan, Wolanczyk and Zinghini 2011, Krathwohl Autumn 2002, Vol 41). Section 2.1 expresses the main message of the game is to educate on the issues SuDS address and the urgency to act, which require the participant to acquire informational knowledge of the current vulnerabilities of urban pluvial flooding due to urbanisation and climate change, as well as understanding and interpreting the role SuDS have in tackling this challenge. Therefore, the main message of the game should convey the learning objective: *1.1*

Knowledge and comprehension of the effects of urbanisation and climate change on urban pluvial flood risk and the urgency for SuDS adoption. Supplementary to that, is to raise awareness of typical household SuDS functions and criteria to build confidence in decision-making when considering SuDS adoption. This is conveyed by the learning objective in the knowledge domain: 1.2 *Knowledge of household SuDS options and associated criteria for their functions and requirements to inform decision-making.* A summary of the decisions and outcomes of Chapter 2.0 is presented in Figure 3.

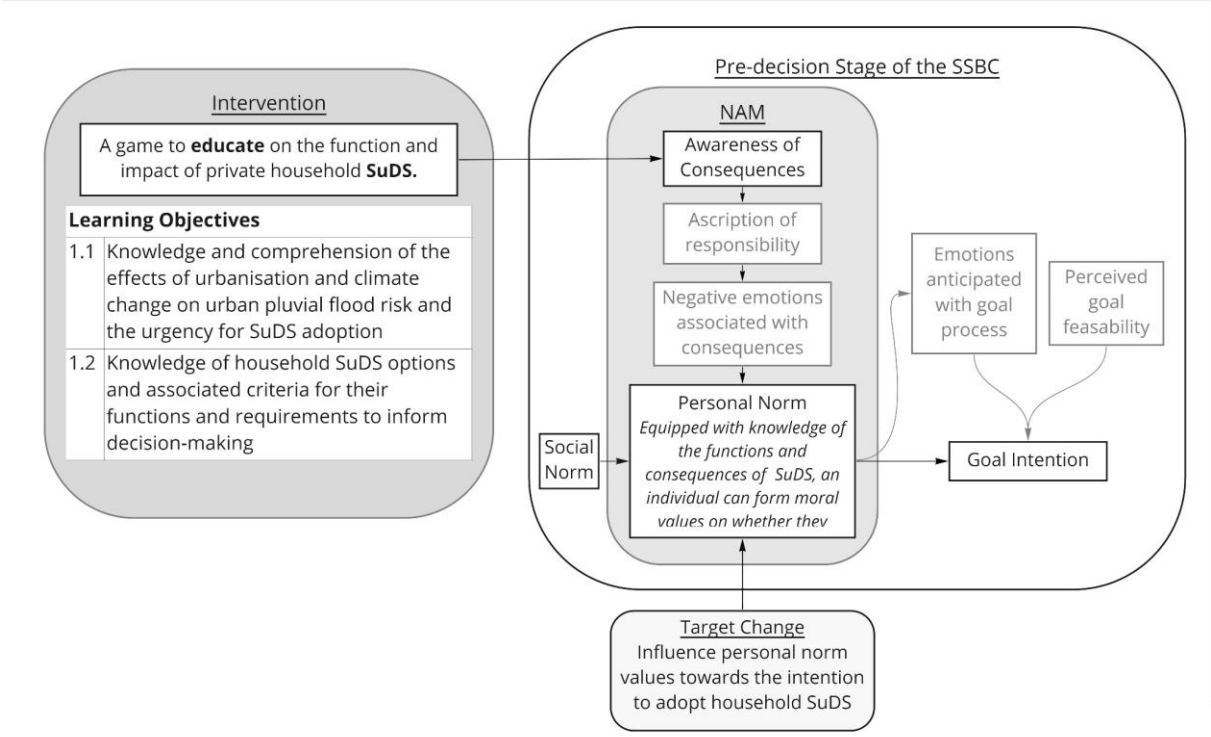

Figure 3 - Summary of outcomes of Chapter 2.0

3.0 Methodology

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

3.1 Serious game design approach

The 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 as shown in Figure 4 (Peters and Westelaken 2014, Mittal, Scholten and Kapelan 2022). This design process is iterative, and the game designer may need to jump between steps and phases to address all aspects of

each phase.

Phase 1 initiates with the formation of the game design specification (GDS), which is informed by the outcomes of Chapter 2.0 to construct clear learning outcomes. The GDS structure follows an adapted Peters & Westelaken (2014) framework for design specifications. The outcome of the GDS will be discussed in section 4.1.

A desk study on the relevant actors, supported by conceptual maps of relevant factors to household SuDS adoption was conducted to inform a full system analysis, which addresses Phase 2. This was followed by a critical selection of system elements most important to convey through the game, considering the GDS, shown in Supplementary Material B. This stage was frequently re-iterated throughout the game design process.

Following that, the relevant system components were mapped on a matrix against typical gaming elements (Peters and Westelaken 2014, Pendleton 2020). The matrix facilitates stimulation of ideas, aiming to express how aspects of the system would translate through elements of a game. This process also stimulated consideration of what the game format would be. Research into other serious games in the field of water and environmental issues presented in literature such as LEVEE PATROLLER (Harteveld, et al. 2010) and GBGame (Juan and Chao 2015), provided insight into how a balance between play, meaning and reality can be approached. Alongside that, board-game products for entertainment, such as Pandemic: Rising Tide (Z-Man Games 2022), Bärenpark (Lookout Games 2017) and Scoville (TMG 2017) were studied for inspiration on how to translate real-life processes into game dynamics and physical representation on a boardgame. This research supported the decision of a game format, thus, enhancing the matrix to be compatible with the game format.

The final stage of phase 3 was to map out the game visually to create *'the game on paper'*. This involved diagrams and visual maps, which translate the gaming elements, into paraphernalia for a physical boardgame. This stage was highly experimental and initiated several adjustments and re-iterations of all tasks within Phase 2 and 3 of the game design.

Finally, the game was constructed, tested, and improved as part of phase 4. The physical board game largely comprised printed and laminated elements, alongside dice and small tokens. Informal test sessions validated the game mechanics, realism, and provided valuable feedback to refine the game considering; challenge level, complexity, fun, engagement, calibration of scoring and understanding of the learning outcomes. This phase was also a highly iterative process in which all stages of the game design were reviewed. The product is a game

prototype to be used in phase 5 where the game is evaluated in a study with the relevant audience, as detailed in section 3.2.

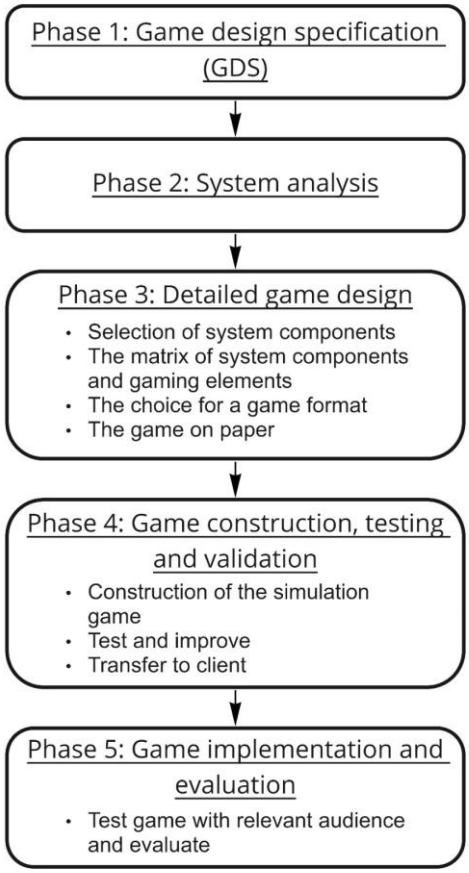

Figure 4 - Peters & Westelaken (2014) four phases of designing a simulation game and Mittal, Scholten and Kapelan (2022) additional fifth phase for game evaluation.

3.2 Game evaluation methods

The method of evaluating the serious game uses a 'quasi-experimental' design in which participants are given a pre and post-game survey (see Supplementary Material C) to evaluate the responses before and after the game session (Baalsrud Hauge, et al. 2013). An exam-style survey is an effective method of capturing learning levels and can be taken remotely online, therefore no additional time for the evaluation needs to be incorporated, appealing to more people's availability in recruitment (Jones, et al. 2009, Vikas and P. 2018). The demographic pre-requisites for participants are adults (18 years of age or older) who live in an urban area. 14 participants were recruited through methods involving sharing of recruitment surveys through leaflets and posters on the campus of TU Delft University and shared in WhatsApp groups of personal contacts to the researcher who would then ask to spread the message through their social media channels. Participants invited to game sessions were also able to invite

friends of theirs. In recruitment, participants were made aware that they would be testing a new educational serious game. Participation of players was voluntary, and no incentives were provided. The demographics of the participants were mostly university students in their 20s due to the audience of the recruitment methods.

Following recruitment and scheduling of participants into 3 game session groups of 4 to 6 participants each, they were asked to fill out a consent form and pre-survey (comprising demographic data collection, knowledge, comprehension, and personal norm data collection) up to 48hours before the game session. Following the 1.5 hour game session, the participants were asked to fill out the post-survey (identical to the pre-survey with the exclusion of demographic data collection and including a gameplay feedback section) up to 48hours after the game session

To identify demographic groups that respond differently to each aspect, relevant demographic data was collected from participants that may define different groups of respondents: age, housing status, education level and how familiar participants are with named household SuDS.

3.2.1 Research method for testing knowledge and comprehension

The serious game aims to educate the public on knowledge gaps regarding private household SuDS as described in section 2.1. To test knowledge acquisition as a result of playing the game, a knowledge test was developed that consisted of multiple choice and open questions to produce score-based test results (Li, et al. 2017, Baalsrud Hauge, et al. 2013, Mayer, et al. 2014). Following Mayer et al.'s (2014) recommendation, participants were also asked to assess their learning with participant self-reporting on understanding/awareness level on the learning objective topics.

To enhance the quality of the research, it is recommended that the data captured with the survey should be as quantitative as possible to reduce subjective interpretation of responses (Baalsrud Hauge, et al. 2013). Multiple choice questions are a straightforward method to produce quantitative data, however, risk bias in the question form, and content (Al-Faris, et al. 2010). Therefore, a survey validation test was conducted with 9 participants comprising 3 Master's students in the field of Water Management and the rest with no knowledge of the subject. The online survey itself was tested with open text feedback to collect comments. This validation captured issues such as technical and accessibility issues with the online survey, bias, obvious answers, confusing question forms, and ambiguous answers. This informed a

survey re-design for clarity of results which used open questions for richer, more representative responses (Reja, et al. 2003). The survey's open questions are restricted to three questions on knowledge acquisition to reduce subjectivity risk. The open questions are formed such that certain keywords can express knowledge level, without the reliance on subjective inference of answers. Analysis of the responses can be based on these keywords.

3.2.2 Research method for testing personal norm stance

The serious game is an educational intervention which targets participants' awareness of the consequences of the household SuDS. As defined in the pre-decision stage of the SSBC considered in section 2.3, the intervention should affect a person's personal norm towards household SuDS adoption. To evaluate this, the participant's personal norm stance is evaluated in the survey. Statements on behavioural intentions and attitudes are presented with a 5-point Likert scale from 'Strongly disagree' to 'Strongly agree' to capture self-reporting of behavioural intention and attitudes towards household SuDS adoption on a scale of agreement.

3.2.3 Evaluating game feedback

To get a comprehensive view of the limitations of the study, it is also useful to capture participant feedback on the game experience itself. Within the post-survey, statements on aspects of the game engagement, challenge level, fun, realism, and playability are presented on a 5-point Likert scale from 'Strongly disagree' to 'Strongly agree'. Following that, two open questions on what the players learnt from the game, and how they would improve the game are asked. The purpose of this is to identify limitations of the game itself that may impact the message of the game and to identify further work and recommendations for similar game design.

3.2.4 Data analysis method

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

The questions answered on Likert scales, were processed to correlate to a numerical value on a scale of 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.

For the open questions, keywords for each response were identified. All responses that featured an answer that fit a correct keyword answer was considered a correct response and all responses that did not or stated 'I don't know' were considered incorrect. For further analysis, the keyword responses were also categorised into different topics of considerations for each question. This assisted qualitative analysis as this indicated how different aspects of the questions were considered.

4.0 The game: Sudsbury

4.1 Game design specification (GDS)

The GDS is the product of the first phase of the game design. It translates the intended objectives of the game, to criteria that the final game should fulfil. The GDS is approached with check-list style questions for which the responses provide direction for the game design process while acting as criteria for validating the final game. The questions proposed in the GDS are adapted from the suggested specification checklist questions of Peters and Westelaken (2014), and cover the following themes: *background problem, objectives of the game, general considerations, elements of the game* and the *use of the game*. The detailed GDS in contained in Supplementary Material D.

A summary of the main game deliverables as set out in the GDS is that the themes within the game should reflect realistic issues surrounding SuDS adoption, specifically applied to the public role in adopting household SuDS in the urban environment. To appeal to the player as a meaningful experience, the game should balance three objectives; play, meaning and reality equally (Harteveld, et al. 2010).

Other general considerations are to convey the message of the game realistically while allowing players freedom of choice with the game actions. The players should be presented with a range of roles and means within the game, that also reflect reality. The game criteria should be reflected through scoring mechanisms, and the winning aim of the game should be to score highly in criteria related to overland flood storage and quality of living simultaneously.

Other more practical specifications for the game are; gameplay time limit that maintains engagement level and physical game portability that is appropriate for the research set-up.

4.2 Description of Sudsbury

4.2.1 Game setting and objectives

Sudsbury is a 4 to 6-player table-top boardgame where the board, shown in Figure 5, spatially represents the hypothetical urban neighbourhood of Sudsbury. Players can each assume 6 unique roles with access to build on their associated housing blocks on the board. The roles have tailored means and conditions according to the role description (example shown in Figure 6) and make the distinction between inhabitant groups who are owners/renters, have and don't have gardens, and those who live in houses or apartments.

The introduction to the game sets the scene that Sudsbury is having issues with pluvial flooding, however, has failed to secure funding to upgrade its sewers. Therefore it is up to the inhabitants (players) to reduce pluvial flooding while also improving 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 qualities that contribute towards quality of living.

The winning aim of the game is to reach *good* liveability scores and increase flood reduction scores such that the town can survive weather events. All players contribute towards this aim in a cooperative manner where all loses and gains affect all players. For instance, a flood affects all, and a low liveability score translates to a low income for all, (and vice versa). If the game is won, the game is won by all, however, the player who has contributed the most to the overall scores receives the glory of being the individual winner.

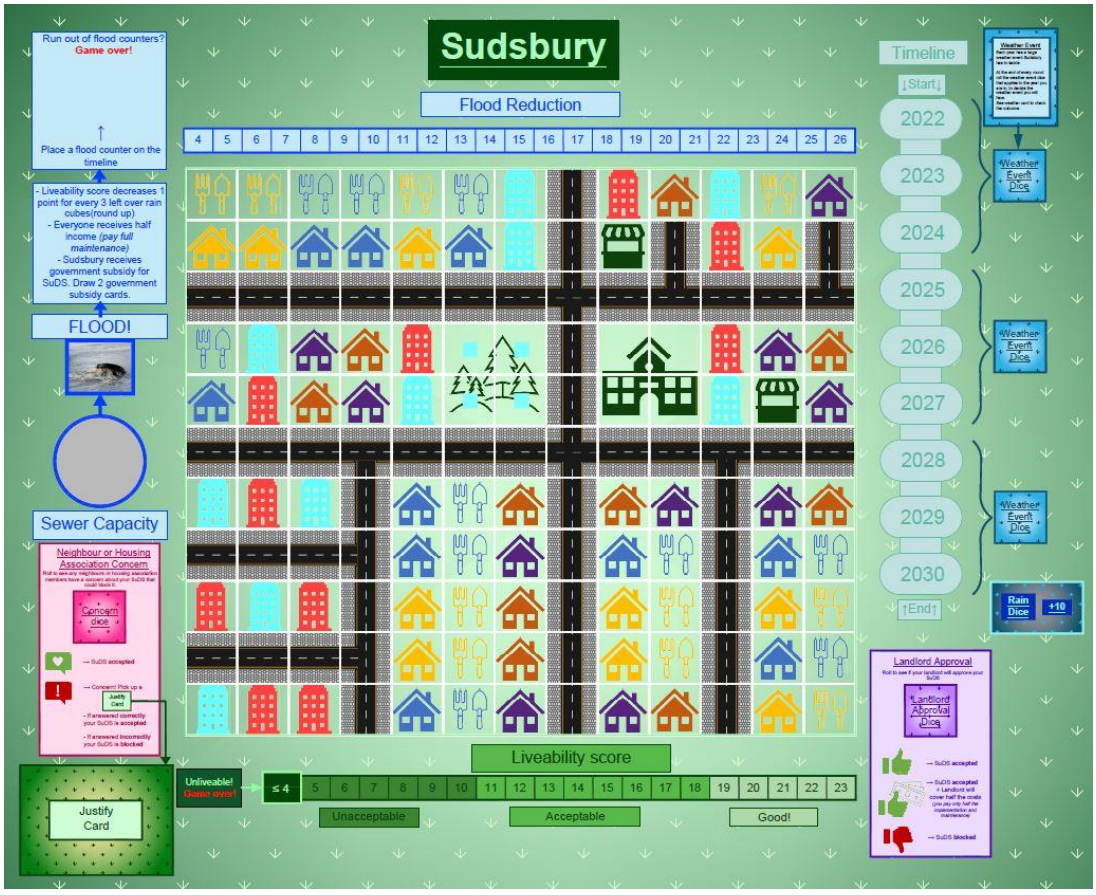

Figure 5 - Game board for Sudsbury

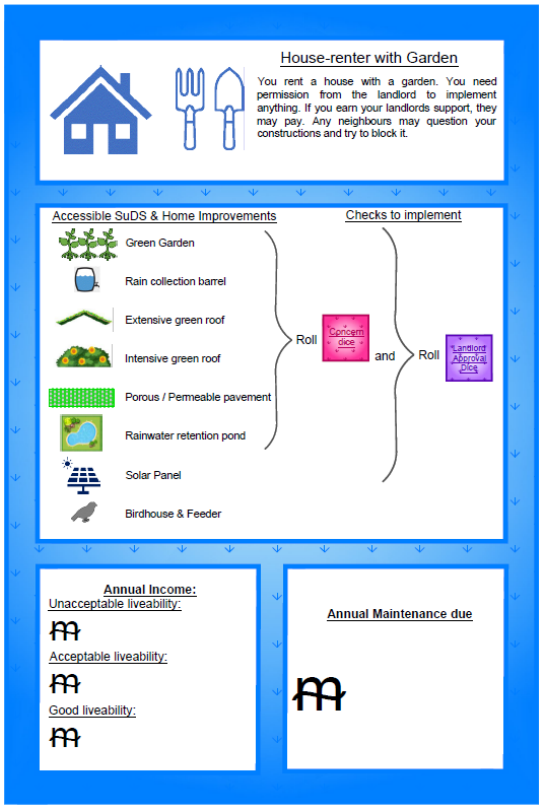

Figure 6 - Sudsbury: Example of a role card for the role 'House-renter with garden'

Figure 7 - Sudsbury: Means cards containing descriptions and criteria for each means

4.2.2 Game structure

The game is structured in rounds that represent the years 2022 to 2030 (9 rounds in total). After every round a weather event occurs, annual income and maintenance is paid. Within this timeline, 2 interventions to the board are made to remove parks in Sudsbury and replace them with housing. This represents urbanisation of the town, and as a consequence, the flood reduction and liveability scores reduce to reflect this. Within every round, each player has a turn to make one action. An action can be to implement/purchase a means for their land, repair up to 2 failed means, remove a means, or pass.

4.2.3 In-game means

Through actionable means, players can influence liveability and flood reduction scores through implementable means. There are eight means available, each with description cards shown in Figure 7, six of which are SuDS, two are home improvements, and access to them depends on player roles. For instance, only roles with gardens can implement garden SuDS. All means have a certain score in improving flood reduction and liveability, as well as initial costs and annual maintenance costs. These scores and costs are based on a scale that represents real-life impact (Krijnen 2020).

To implement a means, the roles have conditions they need to satisfy first. For all SuDS, all players need to roll a concern dice, which they are rolling for the chance that a neighbour, or member of the housing association raises a concern about the proposed SuDS. There is a 1/3 chance of receiving a concern in which the player can answer a justify card correctly to convince the neighbour to accept the SuDS. If answered incorrectly the SuDS is blocked. For renters only, players need to roll an additional dice for SuDS to check if the landlord accepts the means. The landlord dice has a 1/3 chance of blocking, accepting, and accepting with a financial contribution.

4.2.4 Weather events

The weather events that occur at the end of every round/ year comprise rain events and droughts and are decided by the roll of a dice. The outcomes of each weather event are detailed on a *Weather event card* shown in Figure 8. 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 Sudsbury's sewers and land (represented on the *flood reduction* scale) have to handle. As time progresses in the game, the chance of getting a more extreme weather event is more likely as the dice faces include a severe drought and increased rain multipliers.

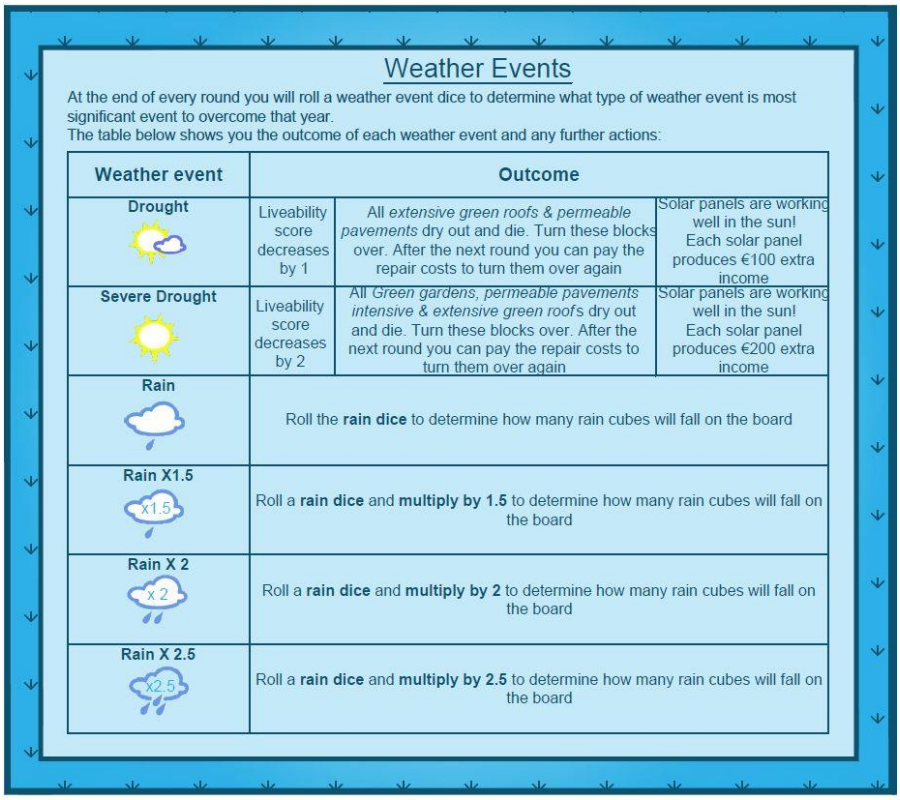

Figure 8 - Weather event card to explain outcomes of each weather event

4.2.5 Losing conditions

The mechanism to flood is when a rain event, and *rain dice* roll (including multiplier), yields a numerical value that exceeds the sum of the sewer capacity (15) and the current flood reduction score. This represents a rain event that saturates all overland SuDS and the sewer capacity. Therefore, the mechanism to flood is partially based on chance, and on how the players can improve the flood reduction score using SuDS. The game is pre-set with flood counters (3 for 4 players, 2 for 5-6 players), which can be placed on the timeline when a flood occurs. Other consequences of a flood are reductions in *liveability* scores, reduction in income for that year, and receiving a *government subsidy* of 2 random SuDS in which the item will be cheaper to implement for the rest of the game. If the players run out of flood counters, it is game over for all. Similarly, if the liveability score reaches the minimum value of 4, then it is also game over for all.

See Supplementary Material E for further details of the game paraphernalia.

5.0 Sudsbury evaluation results

Sudsbury was tested on a participant group of 14 adults living in urban areas. Their ages ranged from 20 to 37 years and comprised 4 free lodgers and 10 renters. The education levels of the group ranged from Level 2 to 7 EQF levels (European Qualifications Framework level). Initial awareness of household SuDS within the participant group was captured to find that no participants have had or currently have any household SuDS, through the majority of participants knew what the most common household SuDS were, namely; garden pond, vegetated garden, green roof, permeable/porous pavement, rain collection barrel.

The overall summary of survey results per survey section is presented in Figure 9 and Figure 10 where average results across the 14-participant group are shown. Details of the results are shown in Supplementary Material F.

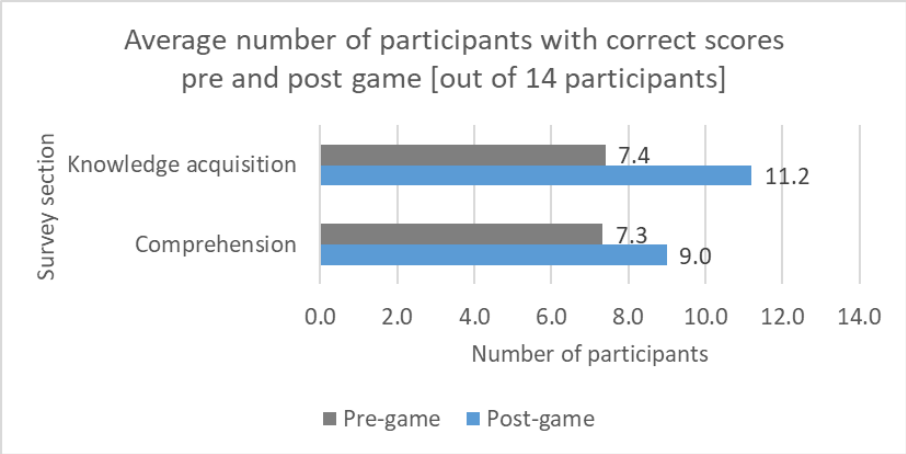

Figure 9 - Summary of results for the survey sections; knowledge acquisition and comprehension

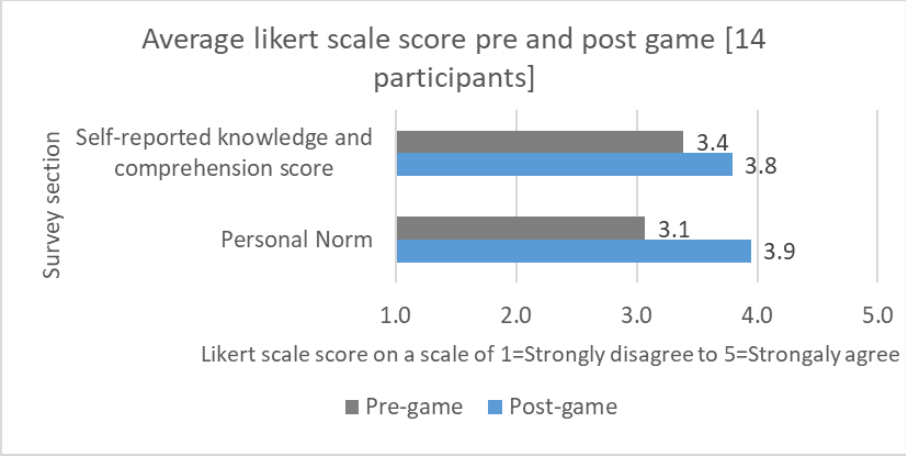

Figure 10 - Summary of results for the survey sections; personal norm and self-reported knowledge and comprehension

5.1 Results of knowledge and comprehension

The results show an increase in group average knowledge and comprehension gained after the game, represented in the knowledge and comprehension question sections shown in Figure 9, and the self-reported learning survey section shown in Figure 10. Every question or statement indicated a group average increase except one comprehension question (C.2 How does infiltration of rainwater affect pluvial flooding?) that did result in a decrease in correct answers after the game. The largest improvement is in the knowledge acquisition section.

The results of the self-reported learning section show (Figure 11) that the pre-game awareness level of topics (statements S1-S5) related to learning objective 1.1 (on the matter of the urgency to act in the context of urbanisation and climate change) are significantly higher than initial awareness levels on topics (statements S6-S9) relating to learning objective 1.2 (Household SuDS). Subsequently, the improvement in awareness level of learning objective 1.2 topics after the game is significantly higher than for learning objective 1.1 topics.

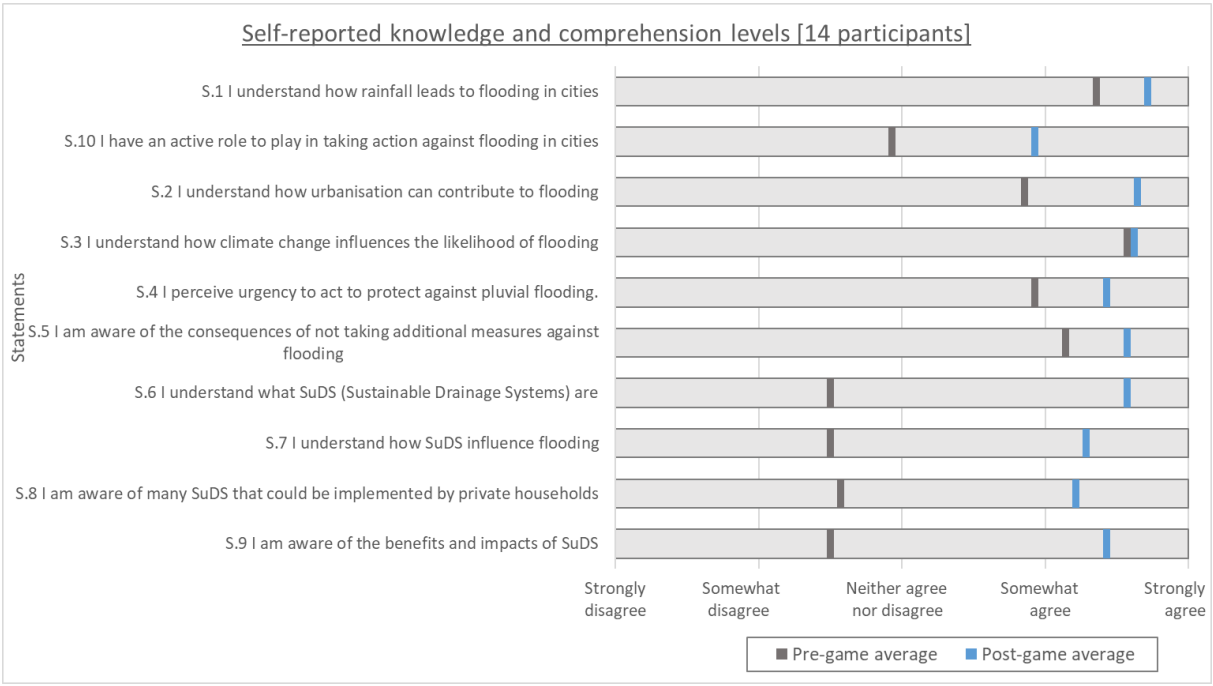

Figure 11 – Pre and post-game average score of 14 participants on a scale of strongly disagree to strongly agree for statements of self-reported knowledge and comprehension levels of household SuDS

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, through did not capture full descriptive sentences. This is shown in Supplementary Material F (, and)

5.2 Results of personal norm attitudes to SuDS

The results of participants' personal norm stances on SuDS adoption are shown in Figure 12 where all statements that pertain to acceptance of household SuDS observe an increase in acceptance after the game of similar scales.

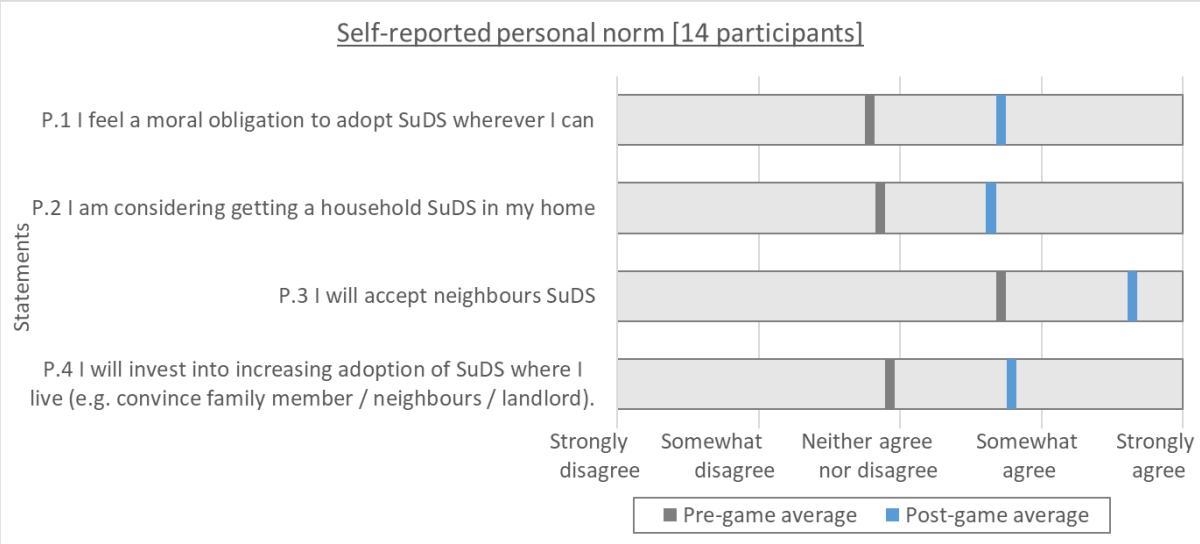

Figure 12 - Pre and post-game average score of 14 participants on a scale of strongly disagree to strongly agree for statements P.1-P.4 of personal norm attitudes towards household SuDS

5.3 Gameplay experience feedback

Following the game, participants provided feedback on the gameplay experience on a scale of agreement shown in Figure 13. Overall, the groups strongly agreed that the game was fun, engaging, and the rules were clear. The group somewhat agreed that the game was realistic, and they learnt a lot in the game. The group agreed that the game was easy to follow and neither agree nor disagreed that the game was easy to win.

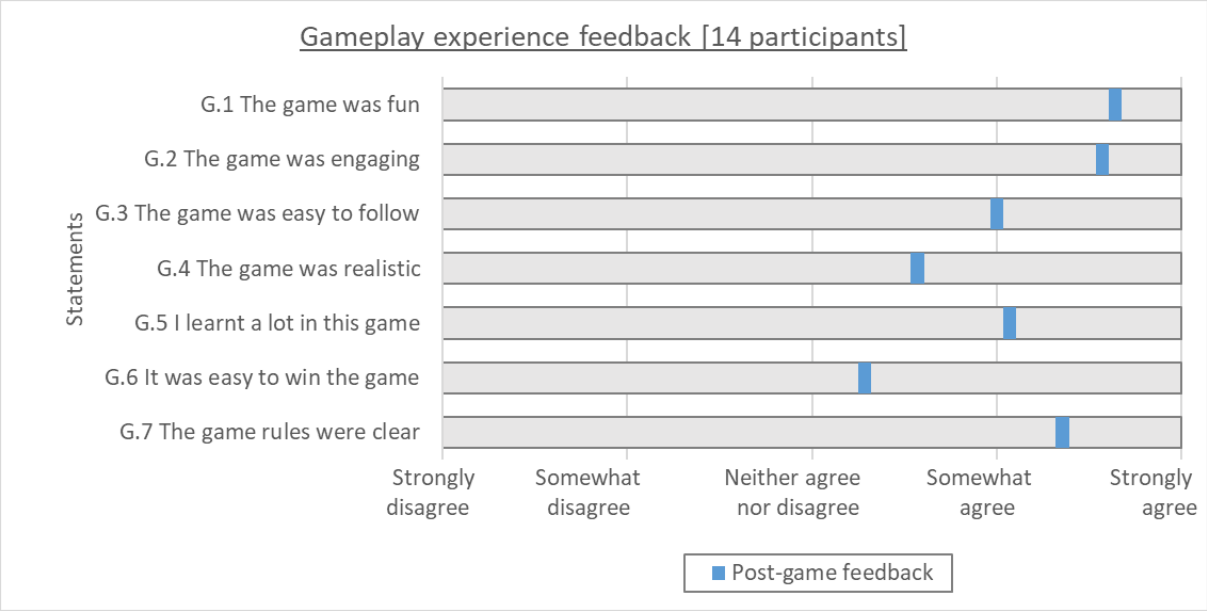

Figure 13 - Pre and post-game average score of 14 participants on a scale of strongly disagree to strongly agree for statements G.1-G.7 of gameplay experience

Full responses to open questions are presented in Supplementary Material F. On the topic of entertainment, responses contained statements such as; "*it is a nice game!"* and *"it was engaging."*. On the topic of game realism, responses contained statements such as; *"Adjust the sewer capacity", "make it a tradeoff between water absorption and money"* and *"Trying to be more realistic. Not all people are available to implement water SUDS;"*. On the topic of the games focus on learning, responses contained statements such as; "*I have learned about suds*" and "*I learned a lot*". Three participants mentioned that were surprised to learn that SuDS in general or specific household SuDS can impact flooding. Three participants mentioned they were surprised to learn that 'we' as the public, or individual households could impact pluvial flood risk. On the topic of challenge or difficulty level of the game, a response was "*Make it a bit harder*.". On the clarity of game rules and ability to follow the game, responses contained statements such as; "*Game Rules could be more specified"* and "*It was very clear for me."*.

6.0 Discussion, Limitations and Recommendations

6.1 Game design method

The game design method followed the stages of the framework presented in Figure 4. Despite Peters & Westelaken (2014) stating the framework for game design is iterative, upon reflection, the process is more circular and iterative than expected where certain tasks or aspects could be skipped or only briefly considered in the early iterations. It was discovered that in phase 1,

elements of the GDS could not be addressed without prior consideration of the selection of system components, which in the framework, would follow the GDS in phase 3. In practice, it is not unmanageable to address sections of the GDS that respond to the selection of systems components such as *game image of reality* and *main actors* on an iterative basis. However, it should be made clear in the framework that these decisions do not have to be made as linearly as the phases are presented to avoid being stuck in the design process and avoid temptation to make premature, ill-considered decisions.

Another example is with the task to populate a matrix of system components and gaming elements in phase 3. Here, additional input on game element considerations was sought from Pendleton (2020) to comprehensively consider all game element aspects. Here a wide range of possibilities could be brainstormed for how a game element could represent a system component. While this is a useful starting point to consider the many ways the system could be represented, it can be extensive and time-consuming if a decision or shortlisting of game formats is not made at an early stage in this process. Here it is recommended that considerations of the game format are made laterally with the matrix task.

The matrix task in particular was a highly creative process that requires brainstorming sessions and research into existing game approaches. It is recommended that within phase 3 of the game design framework, creatively stimulating exercises are suggested. These can be in the form of mind-mapping, visual diagrams, and team collaboration focus groups.

6.2 Testing procedure

The game Sudsbury was tested on 14 participants with very limited demographic reach. The age range of participants was mostly between 20 and 30 years old, and only renters and free lodger inhabitants were included. This restricted the ability to make distinctions between responses of different demographic groups. The recruitment method favoured younger, student groups as it was largely university-based, so recruitment should be more far-reaching to appeal to a wider range of demographic groups, particularly homeowners and those aged 30 or older to capture a more representative impact of the game on the target audience.

The Likert scales of agreement in the survey produced very useful and clear results for the evaluation of the game. However other aspects of the survey design could be improved to produce better quality responses. For example, it was the expectation (explained in section 3.2.3) that the inclusion of open questions would produce rich responses, however many of the responses were still short statements, and not very descriptive. Reja, et al. (2003) recommend

that larger text entry box sizes can encourage richer responses. Furthermore, it is likely that engagement in the process diminished at the post-survey stage, resulting in lower effort given for the post-survey. An alternative post-game evaluation method would be a more interactive debriefing/discussion session to capture richer, meaningful responses (Grund and Schelkle 2020).

The results of the game evaluation (section 5.1) express lower improvement in comprehension learning than knowledge acquisition. This discrepancy could also be attributed to the survey design. The comprehension section of the survey only contained 3 multiple choice questions. These questions may not be focused or framed clearly enough to avoid ambiguity of interpretation to accurately capture comprehension level. This applies to question C.2 in particular that resulted in a decrease in correct answers after the game. Upon reflection, an answer of question C.2 that was considered incorrect could be true in certain circumstances that were not explained in the question. As comprehension is the ability of the individual to understand, interpret and discuss concepts, it would be more suitable to present scenario-based explanation questions to expel ambiguity. These presented in an open question survey, or discussion session would be able to capture a richer, therefore a more representative picture of participant comprehension level. In addition, full comprehension of a concept can require time and reflection therefore, the game session time limit of 1.5h hours could have been a limiting factor for participant comprehension growth. Although two out of the three game sessions were able to complete and win the game within 1.5 hours, and gameplay feedback indicate engagement levels were good, completion, engagement and even winning the game does not mean the player has fully comprehended the messages of the game. 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 argumentation of the effectiveness of serious gaming as an intervention for public education of household SuDS, the more rigorous randomised controlled trial (RCT) testing approach could be conducted. An RCT would 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, demonstrations, or public awareness publications (Baalsrud Hauge, et al. 2013, Mayer, et al. 2014). An example is in a school setting where physics learning was tested with the *Electromagnetism Supercharged!* game where the performance of a group that played the game was compared to a control group where traditional teaching was conducted with the same learning objectives. From this method, the study could

conclude that playing of the game improved performance in understanding (Squire, et al. 2004). The outcome would be a comparative analysis of serious gaming against other educational interventions that would not only produce valuable advice for public engagement methods on SuDS issues, but also strengthen serious game argumentation as an effective medium to raise public awareness in general.

Finally, it should be acknowledged that the test group knew the game was educational and some participants have personal relation or mutual relation to the researcher. In addition, the researcher facilitated the game session, therefore able to build a rapport with participants. These factors can create experimental bias where the participants are influenced to try to meet the expectations of the researcher, affecting the quality and accuracy of the results to favour increased learning outcomes following the game. To minimise this bias, 'blind' protocols should be taken (Holman, et al. 2015). This can involve recruiting participants with no personal relation to the researcher, withholding the purpose of the game from the participants, and to use an independent facilitator for the game, who is not aware of the study goals.

6.3 Game performance

The GDS states the game should balance play, meaning and reality equally. Gameplay experience feedback shows that the game delivered well on aspects of play such as fun, engagement and entertainment. While feedback on game meaning and reality were 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 room for improvement in focusing the game on education, as the group *somewhat agreed* that they learnt a lot in the game. Similarly, the gameplay feedback showed more room for improvement in the realism of the game. Much of the feedback to improve the game were suggestions to make the game more realistic. As the meaning of the game is to educate on the complex system surrounding SuDS, it is argued that the game's accuracy in representing reality does impact success in learning, hence meaning.

Upon reflection, the reality of the system may have been compromised in the game design process in favour of simplification to ensure the game was easy to follow, however, gameplay feedback shows that participants did not find the game difficult to follow, and agreed the game rules were clear, therefore there is potential to re-design the game to incorporate more complex elements of realism.

The area of greatest learning improvement is in knowledge acquisition, however, improvement in knowledge acquisition was not equal between the two learning objective topics. There were higher initial awareness levels on the topic of objective 1.1 (urgency to adopt SuDS in the context of urbanisation and climate change) than for objective 1.2 (household SuDS functions and requirements). Both are topics that were recognised in literature (section 2.1) to have low public awareness levels, however, this study recognises there is a disparity in initial awareness levels between these topics. While the results of the self-reported learning section show significantly higher improvement in learning objective 1.2 than 1.1 topics, it should be noted that there was less 'room for improvement' in awareness of objective 1.1. This is demonstrated with statement S.3 (*I understand how climate change influences the likelihood of flooding*) which addresses learning objective 1.1 where initial awareness levels are the highest out of all statements and there were no change to average awareness level captured after the game. To ensure the game educates on learning objective 1.1 effectively, the game should be re-designed to acknowledge these existing awareness levels, and target more appropriate learning taxonomies, therefore having greater impact. This could involve building from the initial knowledge levels of learning objective 1.1 and focusing more on higher levels of Bloom's taxonomy such as more on the comprehension taxonomy, and also addressing the apply taxonomy which would involve applying and examining knowledge to solve scenario-based problems such as different extreme weather types in a city-builder game (Buchanan, Wolanczyk and Zinghini 2011). Further work to re-design the game for higher levels of Blooms taxonomy can build upon the study of Buchanan, Wolanczyk and Zinghini (2011) to support the development of a serious game taxonomy that addresses Bloom's taxonomy levels.

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. There was one comprehension question (C.2) that scored particularly low after the game on the subject of how infiltration impacts pluvial flooding. Upon reflection, the game did not accurately represent infiltration processes well by equating infiltration to retention within the game mechanics. This emphasises the importance of accurate game realism and is exemplary of the pitfall of over-simplification in a serious game. To improve game realism, distinction in the game mechanics should be made for SuDS that infiltrate, retain, attenuate, convey, filter and collect as a resource.

Through raising awareness, the study supports the SSBC and NAM model discussed in section 2.3, as it recognises that the educational game intervention can impact personal norm stance to favour household SuDS adoption. All statements on attitudes towards SuDS adoption (P.1-P.4) show increased agreement to support SuDS. The statements regarding personal SuDS action (P.1, P.2 and P.4) improved from below neutral positions to positions of agreement. This demonstrates that where there were initially no or opposing attitudes towards SuDS adoption, Sudsbury can activate personal moral obligations to support SuDS. Personal norm stance on acceptance of neighbouring SuDS adoption (P.3) also improved from 'somewhat agree' to almost 'strongly agree', showing that the impact on personal norm attitudes extend to concern a '*wider picture'* as attitudes towards neighbours SuDS are more accepting.

The impact of the game on personal norm stance demonstrates that the serious game can influence behavioural change within the pre-decision stage of the SSBC through raising awareness. Further work would be to assess the impact of the game on long-term awareness level and personal norm monitoring. As an extension of that, the study could further confirm the SSBC model by collecting data on any changed behaviours, such as actions to support household SuDS adoption. This would confirm the game's performance and ability to educate for changing public behaviours.

Overall, Sudsbury is an educational game that has potential in raising awareness of household SuDS within the general public which can impact personal norm to create growth in a market of inhabitants that are willing to support and adopt household SuDS. While the game plays 4 to 6 players, it is reproducible and translatable to reach a wider audience. The game could be promoted by municipalities to engage with their community or shared by housing association groups or individual inhabitants who want to make local neighbours more receptive to household SuDS.

7.0 Conclusion

This paper presented a serious game designed to educate urban inhabitants on household SuDS to address the barrier of public lack of knowledge and awareness of SuDS. A table-top boardgame named Sudsbury was designed to represent the impact of household SuDS on a neighbourhood scale. A group of 14 participants tested the game and were evaluated in knowledge acquisition, comprehension, and personal norm stance before and after playing the game in a qualitative and quantitative survey. The key findings of the study are;

- The game Sudsbury can educate citizens on the topic of private household SuDS in both knowledge and comprehension, with the most significant improvement in

knowledge acquisition of what household SuDS are.

- Through raising awareness, the game did impact personal norm stances to be more agreeable with household SuDS adoption.
- Sudsbury appealed well to the play aspect of gaming, however, improvements could be made to emphasise the meaning and realism of the game by expressing concepts such as ground infiltration more realistically to promote better comprehension of concepts.
- Prior understanding of public awareness levels in the specific learning objective topics would allow the game design to be targeted better towards the appropriate learning taxonomy level, therefore having a greater impact.
- The game design process was a far more circular and iterative process than expressed by Peters and Westelaken (2014).

Sudsbury is demonstrative of an educational game designed to specifically to Bloom's taxonomy levels that raises awareness to impact behavioural change within the pre-decision stage of the SSBC through changing personal norm stance to favour household SuDS adoption. It is a public engagement method that could be distributed to create growth and support for household SuDS adoption in the urban environment.

Finally, we acknowledge 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 urban inhabitant population. The study was also limited in time scale. Further study could monitor participants over a longer time period to evaluate long-term impact on learning and behavioural change, as well as the impact of multiple play sessions of Sudsbury. To enhance the quality of results, a post-game debriefing/discussion session could capture richer responses, and the game studied in an RCT could strengthen the argumentation for serious games as a public education method.

References

Al-Faris, Eiad A, Ibrahim A Alorainy, Ahmad A Abdel-Hameed, and Mohammed O Al-Rukban. 2010. “Medical Education A practical discussion to avoid common pitfalls when constructing multiple choice questions items.” *Journal of Family and Community Medicine* (Journal of Family and Community Medicine) 91 - 97.

Amsterdam Rainproof. 2022. *The Measures Toolbox.* 30 May. https://www.rainproof.nl/toolbox.

Aubert, A. H., Bauer, R., Lienert, J. 2018. “A review of water-related serious games to specify use in environmental Multi-Criteria Decision Analysis.” *Environmental Modelling and Software Vol 105* 64 - 78.

Baalsrud Hauge, J., E. Boyle, I. Mayer, R. Nadolski, J. C. K. H. Riedel, P. Moreno-Ger, F. Bellotti, T. Lim, and J Ritchie. 2013. “Study Design and Data Gathering Guide for Serious Games’ Evaluation.” *Psychology, Pedagogy, and Assessment in Serious Games* 394 - 419.

Bamberg, Sebastian. 2013. “Changing environmentally harmful behaviors: A stage model of self-regulated behavioral change.” *Journal of Environmental Psychology* 151 - 159.

Bassone-Quashie, Yena. 2021. *Transitioning to a sustainable urban water future in the Netherlands.* Thesis, Delft: TU Delft.

Bloom, Benjamin S, Max D Engelhart, and Edward J Furst. 1968. *Taxonomy of Educational Objectives : The Classification of Educational Goals. Handbook 1. Cognitive Domain.* New York: MacKay.

Boogaard, Floris C., Guri Venvik, Rui L.Pedroso de Lima, Ana C. Cassanti, Allard H. Roest, and Antal Zuurman. 2020. “ClimateCafe: An interdisciplinary educational tool for sustainable climate adaptation and lessons learned.” *Sustainability (Switzerland).*

Brown, R R, and M A Farrelly. 2008. “Sustainable Urban Stormwater Management in Australia: Professional Perceptions on Institutional Drivers and Barriers.” *11th International Conference on Urban Drainage.* Edinburgh.

Brown, R. R., & Farrelly, M. A. 2009. “Delivering sustainable urban water management: A review of the hurdles we face.” *Water Science and Technology, 59(5),* 839–846.

Buchanan, L, F Wolanczyk, and F Zinghini. 2011. “Blending Bloom's Taxonomy and Serious Game Design.” *2011 International Conference on Security and Management.* Las Vegas.

Buurman, J. J.G., T. K. Lee, M. S. Iftekhar, and S. M. Yu. 2021. “Strategies to promote the adoption of sustainable drainage by private developers: a case study from Singapore.” *Urban Water Journal* 61 - 67.

Cettner, Annicka. 2012. *Overcoming Inertia to Sustainable Stormwater Management Practice.* Luleå: [Doctoral Thesis, Luleå University of Technology] Luleå tekniska universitet.

Cheng, Meng Tzu, and Len Annetta. 2012. “Students' learning outcomes and learning experiences through playing a serious educational game.” *Journal of Biological Education* 203 - 213.

David Michael, Sande Chen. 2006. *Serious games: games that educate, train and inform.* Boston, MA.: Thomson Course Technology.

de Groot, Judith I.M., Krista Bondy, and Geertje Schuitema. 2021. “Listen to others or yourself? The role of personal norms on the effectiveness of social norm interventions to change pro-environmental behavior.” *Journal of Environmental Psychology.*

Esmail , B A, and L Suleiman. 2020. “Analyzing evidence of sustainable urban water management systems: A review through the lenses of sociotechnical transitions.” *MDPI Sustainability.*

Ewen, Tracy. 2016. “Learning about water resource sharing through game play.” *Hydrology and Earth System Sciences Discussions* 1 - 12.

Gifford, Robert. 2014. “Environmental psychology matters.” *Annual Review of Psychology* 541 - 579.

Grund, Christian Karl, and Michael Schelkle. 2020. “Developing Serious Games with Integrated Debriefing: Findings from a Business Intelligence Context.” *Business and Information Systems Engineering* 87 - 101.

Harteveld, Casper, Rui Guimares, Igor S. Mayer, and Rafael Bidarra. 2010. “Balancing Play, Meaning and Reality: The Design Philosophy of LEVEE PATROLLER.” *Simulation and Gaming* 316 - 340.

Holman, Luke, Megan L Head, Robert Lanfear, and Michael D Jennions. 2015. “Evidence of Experimental Bias in the Life Sciences: Why We Need Blind Data Recording.” *PLoS Biol 13(7).*

Jan Kyselý, Ladislav Gaál, Romana Beranová. 2011. “Climate change scenarios of precipitation extremes in Central Europe from ENSEMBLES regional climate models.” *Theoretical and Applied Climatology Vol 104* 529 - 542.

Jeffrey, P., and R A.F. Seaton. 2004. “A Conceptual Model of ‘Receptivity’ Applied to the Design and Deployment of Water Policy Mechanisms.” *Environmental Sciences* 277 - 300.

Jha, A.K., Bloch, R., Lamond, J. 2012. *Cities and Flooding: a Guide to Integrated Urban Flood Risk Management for the 21st Century.* Washington, D.C.: The World Bank.

Jones, Karl O., Janice Harland, Juliet M.V. Reid, and Rebecca Bartlett. 2009. “Relationship between examination questions and bloom's taxonomy.” *Proceedings - Frontiers in Education Conference, FIE.* San Antonio, TX: Frontiers in Education Conference, FIE.

Juan, Yi Kai, and Tseng Wei Chao. 2015. “Game-based learning for green building education.” *Sustainability (Switzerland)* 5592 - 5608.

Keller, Anna, Charis Eisen, and Daniel Hanss. 2019. “Lessons learned from applications of the stage model of self-regulated behavioral change: A review.” *Frontiers in Psychology.*

Kim, J. H., Y.H. Kim, and F Demarie. 2017. “Facilitators and Barriers of Applying Low Impact Development Practices in Urban Development.” *Water Resources Management 31* 3795 - 3808.

Kirschner, Paul A., and Carl Hendrick. 2020. *How Learning Happens.* How Learning Happens: Routledge, Taylor & Francis Group.

Krathwohl, David R. Autumn 2002, Vol 41. “A Revision of Bloom's Taxonomy: An Overview.” *Theory Into Practice* 212 - 218.

Krijnen, Katrice. 2020. *Increasing the resilience of urban areas to extreme precipitation: Are the residents ready?* Thesis, Delft: TU Delft.

Li, Katie, Mark Hall, Pablo Bermell-Garcia, Jeffrey Alcock, Ashutosh Tiwari, and Mar González-Franco. 2017. “Measuring the Learning Effectiveness of Serious Gaming for Training of Complex Manufacturing Tasks.” *Simulation and Gaming* 770 - 790.

Li, L., Collins, A. M., Cheshmehzangi, A., & Chan, F. K. S. 2020. “Identifying enablers and barriers to the implementation of the Green Infrastructure for urban flood management: A comparative analysis of the UK and China.” *Urban Forestry and Urban Greening, 54(June)* 126770.

Lookout Games. 2017. *Bärenpark.* Accessed 07 14, 2022. https://lookout-spiele.de/en/games/baerenpark.html.

Lukosch, H. K., Bekebrede, G., Kurapati, S., & Lukosch, S. G. 2018. “A Scientific Foundation of Simulation Games for the Analysis and Design of Complex Systems.” *On the Architecture of Game Science* 279 - 314.

MassonDelmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.). 2021. *IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* . Cambridge University Press. In Press.

Mayer, Igor, Geertje Bekebrede, Casper Harteveld, Harald Warmelink, Qiqi Zhou, Theo Van Ruijven, Julia Lo, Rens Kortmann, and Ivo Wenzler. 2014. “The research and evaluation of serious games: Toward a comprehensive methodology.” *British Journal of Educational Technology* 502 - 527.

Mittal, Aashna, Lisa Scholten, and Zoran Kapelan. 2022. “A review of serious games for urban water management decisions: current gaps and future research directions.” *Water Research, Volume 215* 118217.

Nguyen, T T, H H Ngo, W Guo, X C Wang, N Ren, G Li, J Ding, and H Liang. 2019. “Implementation of a Specific Urban Water Management - Sponge City.” *Science of the Total Environment 652* 47 - 162.

Nordlund, Annika M., and Jörgen Garvill. 2003. “Effects of values, problem awareness, and personal norm on willingness to reduce personal car use.” *Journal of Environmental Psychology* 339 - 347.

O’Donnell, E. C., Lamond, J. E., & Thorne, C. R. 2017. “Recognising barriers to implementation of Blue-Green Infrastructure: a Newcastle case study.” *Urban Water Journal, 14* 964–971.

Onwezen, Marleen C., Gerrit Antonides, and Jos Bartels. 2013. “The Norm Activation Model: An exploration of the functions of anticipated pride and guilt in pro-environmental behaviour.” *Journal of Economic Psychology* 141 - 153.

Pendleton, Aaron J. 2020. *Introducing the Game Design Matrix: A Step-by-Step Process for.* Thesis, Ohio: Air Force Institute of Technology.

Pereira, Gonçalo, Rui Prada, and Ana Paiva. 2014. “Disaster prevention social awareness: The stop disasters! case study.” *2014 6th International Conference on Games and Virtual Worlds for Serious Applications, VS-GAMES 2014.*

Peters, V, and M. Westelaken. 2014. *Simulation games - A concise introduction to game design.* Nijmengen: Samenspraak Advies.

Plass, Jan L., Bruce D. Homer, and Charles K Kinzer. 2015. “Foundations of Game-Based Learning.” *Educational Psychologist* 258 - 283.

Rebolledo-Mende, Genaro, Katerina Avramides, Sara de Freitas, and Kam Memarzia. 2009. “Societal impact of a Serious Game on raising public awareness: the case of FloodSim.” *Sandbox '09: Proceedings of the 2009 ACM SIGGRAPH Symposium on Video Games* 15 - 22.

Reja, Urša, Katja Lozar Manfreda, Valentina Hlebec, and Vasja Vehovar. 2003. “Open-ended vs. Close-ended Questions in Web Questionnaires.” *Developments in Applied Statistics.*

ReNUWIt. 2022. *ReNUWit: Education: Pre-College & Public.* Accessed 01 11, 2022. http://www.renuwit.org/drupal/education-pre-college-and-public.

Restemeyer, Britta, and Floris C. Boogaard. 2020. “Potentials and Pitfalls of Mapping Nature-Based Solutions with the Online Citizen Science Platform ClimateScan.” *MDPI Land.*

Roy, A. H., Wenger, S. J., Fletcher, T. D., Walsh, C. J., Ladson, A. R., Shuster, W. D., ... Brown, R. R. 2008. “Impediments and solutions to sustainable, watershed-scale urban stormwater management: Lessons from Australia and the United States.” *Environmental Management, 42(2)* 344–359.

Savic, Dragan A., Mark S. Morley, and Mehdi Khoury. 2016. “Serious Gaming for Water Systems Planning and Management.” *Water (Switzerland), 8(10)* 1–17.

Squire, Kurt, Mike Barnett, Jamillah M Grant, and Thomas Higginbotham. 2004. “Electromagnetism Supercharged! Learning Physics with Digital Simulation Games.” *ICLS '04: Proceedings of the 6th international conference on Learning sciences.* Santa Monica California : International Society of the Learning Sciences. 513–520.

susdrain. n.d. *SuDS components overview.* Accessed 05 03, 2022. https://www.susdrain.org/delivering-suds/using-suds/suds-components/suds-components.html.

Thames 21. 2022. *Thames 21.* Accessed 03 05, 2022. https://www.thames21.org.uk/what-we-do/.

Thorne, C. R., Lawson, E. C., Ozawa, C., Hamlin, S. L., & Smith, L. A. 2018. “Overcoming uncertainty and barriers to adoption of Blue-Green Infrastructure for urban flood risk management.” *Journal of Flood Risk Management, 11* S960–S972.

TMG. 2017. *Scoville.* Accessed 07 14, 2022. http://playtmg.com/scoville/.

Valkering, Pieter, Rutger van der Brugge, Astrid Offermans, Marjolijn Haasnoot, and Heleen Vreugdenhil. 2013. “A Perspective-Based Simulation Game to Explore Future Pathways of a Water-Society System Under Climate Change.” *Simulation and Gaming* 366 - 390.

Vikas, Magar, and Dr. Ghatule Arjun P. 2018. “Use of Questionnaire as Knowledge Acquisition tool for Expert System to Evaluating Teaching Staff Performance in

Technical Education." *International Journal of Innovations & Advancement in Computer Science.*

Wansleeben, Kjell. 2016. *Spatial consequences of circular water systems.* Delft: TU Delft.

White, I. and Howe, J. 2005. "Unpacking the barriers to sustainable urban drainage use." *Journal of Environmental Policy and Planning* 25–41.

Wihlborg, M., J. Sörensen, and J. Alkan Olsson. 2019. "Assessment of Barriers and Drivers for Implementation of Blue-green Solutions in Swedish Municipalities." *Journal of Environmental Management 233:* 706–718.

Williams, J. B., R. Jose, C. Moobela, D. J. Hutchinson, R. Wise, and M. Gaterell. 2019. "Residents' perceptions of sustainable drainage systems as highly functional blue green infrastructure." *Landscape and Urban Planning.*

Winz, I., Trowsdale, S., & Brierley, G. 2014. "Understanding barrier interactions to support the implementation of sustainable urban water management." *Urban Water Journal, 11(6)* 497–505.

Zhonggen, Yu. 2019. "A Meta-Analysis of Use of Serious Games in Education over a Decade." *International Journal of Computer Games Technology.*

Z-Man Games. 2022. *Pandemic: Rising Tide.* Accessed 07 14, 2022. https://www.zmangames.com/en/products/pandemic-rising-tide/.