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The Urban dRain game: Co-developing stormwater management solutions at neighbourhood scale

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ABSTRACT

As cities expand and land becomes built over, more rainwater will run off rather than infiltrate or evapo(trans)pirate, increasing the likelihood of urban pluvial flooding. Stormwater management and planning is essential to ensure that urban areas are well adapted to climate change, involving cooperation between diverse actors with their own objectives. Current tools to support decision-making have a narrow technical focus and do not incorporate the multi-actor context. In this paper, we present a serious game called Urban dRain, developed with the aim to integrate technical assessment of blue, green and grey solutions and actor negotiation. In the game, participants are challenged to develop a stormwater management strategy for a Dutch neighbourhood in multiple rounds, first within their own separate groups, and then collectively. We present results from validation and play-testing the final game prototype with 70 students and researchers. Results show that the game supports socio-technical learning by encouraging players to come up with a range of stormwater management plans and negotiate for their individual goals while achieving a collective goal. The game demonstrates potential to bring actors with varying perspectives together and co-develop solutions to pluvial flooding, overcoming limitations of existing technology-focused tools.

Key words: multi-actor negotiation, serious game, socio-technical learning, stormwater management, SuDS, urban flooding

HIGHLIGHTS

- Platforms that integrate technical assessment with actor negotiations are missing.
- A serious game – Urban dRain is presented where players co-develop solutions to urban flooding.
- Multiple actors with different goals and perspectives are included in the decision-making.
- An Excel-based simplified assessment model is used to assess impacts.
- The game supports socio-technical learning about blue, green, and grey solutions.

1. INTRODUCTION

As cities become more densified, little space is available for stormwater interception or storage, evaporation, and infiltration, thereby increasing surface runoff with high peak flows leading to pluvial flooding (Butler & Davies 2004). Pluvial flooding poses significant economic and public health risks to densely populated cities (ten Veldhuis *et al.* 2010; Sušnik *et al.* 2015). Climate change affects precipitation patterns, increasing the frequency and intensity of extreme rainfall events in Europe (Bednar-Friedl *et al.* 2021), resulting in more pluvial flooding-induced risks. This necessitates upgrading of existing infrastructure to withstand the incoming intense rainfalls. Additionally, more frequent and intense heat waves will expose a large part of the population to higher heat stress, thereby affecting health and well-being. To address the long-term urban drainage demand, effective stormwater management and spatial planning are urgently needed for urban areas.

Multiple socio-technical barriers hinder the development of a stormwater plan for an area. Firstly, the most desirable technical solution is often unclear. Blue, green, or grey solutions applied alone are often not optimal with regard to the goals specified by the actors taking the decision, and a combination of measures is typically required. Even when an optimal technical solution is available, rarely does a single actor have full control over the problem and solution (Qiao *et al.* 2018; Zingraff-Hamed *et al.* 2020). Multiple actors, both private and public entities, are involved in the decision-making around stormwater management and they have different interests and objectives requiring trade-offs to be made (Dhakal & Chevalier 2016). Public actors, such as municipalities and water boards, can implement solutions on public land. However, most urban land is privately owned, meaning that the role of the citizens and private actors is critical in the transition towards a sustainable stormwater management strategy (Hegger *et al.* 2017).

Engaging relevant actors in the design and planning process is beneficial. When citizens are involved early on in the process their concerns can be heard and they are more eager to accept the solutions and maintain them (Dai *et al.* 2018). Typical engagement strategies to involve residents include awareness campaigns via leaflets, social and traditional media, and information meetings targeting residents to take action on their private property (Dai *et al.* 2018). Current strategies to involve actors in stormwater management planning lie at the lower levels of the ladder of citizen participation (Arnstein 2019) and involvement (Dobre *et al.* 2021). Another limitation of these strategies is that they may fail to effectively engage participants or are too complex for non-experts (Sousa *et al.* 2022a). Engaging strategies that can bring actors at a local level together to co-design stormwater management plans are still needed.

The notion of serious games was introduced by Abt (1970) as analog or digital games that are designed not just for entertainment but for a 'serious' purpose such as education, training, behaviour change, and supporting decision-making among many others (Michael & Chen 2006; Djaouti *et al.* 2011). Serious games are an engaging and effective tool to bring actors together and stimulate an understanding of their roles and perspectives (Den Haan & Van der Voort 2018). They facilitate the simulation of decision-making processes, allowing players to engage in iterative learning by making choices and evaluating the consequences of their choices in a safe environment. Simulating decision-making in games can make the perceptions of an actor explicit, and make the conflicting values and interests transparent, which can be further discussed, challenged or negotiated (Armstrong & Hobson 1974).

Serious games have been developed to aid decision-making in the urban environment and by taking into account multiple stakeholders' views (Poplin 2012; Ampatzidou *et al.* 2018; Sušnik *et al.* 2018; Marome *et al.* 2021; Delaney 2022; Sousa *et al.* 2022b). Serious games have also been developed to address different urban water infrastructure challenges (Savic *et al.* 2016; Aubert *et al.* 2018; Mittal *et al.* 2022). However, serious games that are specifically focused on pluvial flooding and related urban stormwater management issues are scarce. In this context, games have been designed to integrate nature-based solutions with urban planning (e.g. Istrate & Hamel 2023) but with focus on related solution space only, i.e. without exploring the combination of traditional grey infrastructure solutions with sustainable urban drainage systems (SUDS). Furthermore, decision-support systems have also been built to support urban stormwater management planning (e.g. Sun *et al.* 2024) but with technical focus on finding an optimal solution for a single decision maker, i.e. without bringing multiple actors together to look into their potentially conflicting objectives and actions. Lastly, according to our best knowledge, games that enable collaborative stormwater management design for building collective solutions have not been designed so far.

In this paper, we present the game concept, development, and prototype of a serious game called *Urban dRain* that addresses the above knowledge gaps. The game is based on a neighbourhood in the Netherlands and is designed to bring public and private actors together to co-develop a stormwater management plan whilst resolving any potentially conflicting views. Players can reach a compromise solution by combining measures to be put in public and private spaces whilst assessing their performance through a decision-support tool. Players are also challenged to negotiate and find a collective solution and come to an agreement on how to distribute the costs among them.

The paper is structured as follows: The next section presents the goals of the Urban dRain game and the case study context for which it was developed, followed by design considerations and components of the underlying decision-support tool. Section 3 presents the game concept along with details on the game storyline, player roles, and progression of rounds. In Section 4, results from gameplay sessions with 70 MSc students are presented. Section 5 discusses the results, improvements to the game, and suggestions for generalization. Finally, Section 6 sums up the conclusions drawn from game design and testing and suggestions for future work.

2. METHODOLOGY

Serious games are designed in phases that could be linear or iterative. Five phases usually underlie serious game design (see, e.g. Duke 1975; Duke & Geurts 2004; Peters & Westelaken 2014; Mittal *et al.* 2022): starting from specifying the goals and requirements of the game (Phase 1), analysing the real-world system (Phase 2), translating the real-world system into the game world (Phase 3), constructing and validating the game (Phase 4), and testing the game with the intended audience (Phase 5). Additionally, while designing games, a key philosophy to keep in mind is to balance the worlds of reality, meaning and play, i.e. the real-world problem, the learning that players can derive from the game, and aspects of fun and engagement (Harteveld *et al.* 2010, Harteveld 2011).

The overall aim of the Urban dRain game is to enable the co-development of a collective stormwater management solution at the neighbourhood scale, whilst integrating and resolving potentially conflicting stakeholder views into the socio-technical decision-making in the case study. The game considers the following social and technical goals:

Social goals:

- Increase awareness about the urban flooding problem among different actors and enable a shared understanding of the problem;
- Increase awareness of the social dynamics of decision-making; relevant actors and their responsibilities, resources, perceived solutions, actions, and goals;
- Realise mutual interdependence among actors and collective responsibility for addressing the problem.

Technical goals:

- Learn about the impact of potential solutions at the individual and collective level;
- Make players appreciate various performance trade-offs by combining blue, green, and grey solutions.

To bring together the technical solutions and actor negotiations, the serious game has to be rooted in both the governance and technical context of a specific case study (Phases 2 and 3). Our game is based on the context of the Netherlands, but the development of the game itself is set up in a framework that can be followed to develop serious games with the same aim as other case studies.

2.1. Urban flooding context in The Netherlands

The Netherlands is one of the leading countries in Europe for urban sprawl, densification, and the amount of surface covered by urban area (Evers & van Schie 2019; Claassens *et al.* 2020). High precipitation levels combined with densely populated, low-lying areas and high groundwater levels further contribute to urban flooding (van de Ven *et al.* 2010). Climate change projections for the Netherlands further indicate more frequent high-intensity rainfall and higher temperatures (van der Wiel *et al.* 2024).

The current national policy in the Netherlands strives to decouple stormwater drainage from the sewer system as much as possible. This is done by separating the two flows and increasing the implementation of blue-green solutions in urban areas (Hegger *et al.* 2017; Ministry of Infrastructure & Water Management 2022). In the Netherlands, municipalities are responsible for urban water management in the public areas, encompassing rainwater collection and processing, while private land owners bear the responsibility for rainwater management on their properties (Dai *et al.* 2018). Next to the municipalities, waterboards are the government bodies who are responsible for managing surface water levels, water quality, wastewater treatment, and groundwater levels, thereby impacting the decision-space of both municipalities and residents. The division and discussion of responsibilities and required actions among residents and municipalities is relatively low, leading to municipalities going beyond their formal duties (Hegger *et al.* 2017). Thus, both public and private actors need to come together to take collective responsibility of the problem and find solutions that are viable in the long run.

We base the Urban dRain game around a Dutch case study to bring public and private actors together and discuss their varying perspectives while technically assessing possible solutions that can be used to overcome pluvial flooding. For the scope of this study, we consider a neighbourhood of 170 households in the medieval centre of a densely populated city in the Netherlands. The case study area is a 22.5-ha residential neighbourhood that mainly consists of impervious areas such as roofs, buildings and streets. There is limited pervious area in the form of small back gardens. The current sewer infrastructure primarily consists of an old brick sewer that runs under a narrow back alley, (originally) laid out in the 1870s and expanded over the years. The pipe runs across the neighbourhood, crossing several plots of private land and the backyards of the houses. The sewer collects stormwater and wastewater from the neighbourhood and conveys it to a pumping station for further transport via the public sewer system. Four combined sewer overflow (CSO) structures discharge excess water during intense rainfall events, three of which discharge in the side canal on the top of Figure 1, the other to the left canal into which the side canal also drains. The water level in both canals is controlled by large pumping stations, transporting the water via major drainage canals towards a nearby river. Currently, the sewer and CSOs do not have sufficient capacity, with the relatively high water level in the canals posing further limitations for draining the neighbourhood. As a result, residents face recurrent pluvial flooding, typically twice every year. Figure 1 shows a simplified representation of the real-world sewer system, in which additional CSOs and related conduits were disregarded, retaining only the one discharging into the side canal, and considering only stormwater re-routing directly to the surface water.

To analyse the real-world system and incorporate it into a serious game, a detailed systems analysis has to be conducted using actor mapping and cognitive mapping. Relevant actors in the case study were shortlisted and interviewed between June and August 2023 and their perceptions were captured using cognitive mapping (see Mittal *et al.* (2024) for details). Several actors were identified to be of key interest for the analysis: the civil engineering and monumental departments of the municipality, the waterboard, and the residents living in the monumental houses in the area. Among these actors, the municipality and residents further emerged as critical as they faced dilemmas with respect to their actions and its consequences on their own goals as well as those of other actors. This concerns the choice of sewer upgrades undertaken by the municipality in the public space and the implementation of SUDS by residents in the private space. Another key concern raised by the residents was the financing and cost distribution of the solutions to be implemented between the municipality and residents. Although it is clear that actors need to cooperate to come up with a solution, they have thus far failed to do so effectively.

2.2. Game design: translating game goals to game mechanics

A socio-technical systems analysis was previously performed to identify and refine the goals of the Urban dRain game (see Mittal *et al.* (2024) for a detailed analysis of the real-world technical and multi-actor context). Thereafter, the first prototype of Urban dRain game was conceptualized and designed between February and May 2024, followed by testing and iterative improvements from June to October 2024. Various design choices were made to translate the goals of the serious game into the gaming world. This entails defining the rules and mechanisms that govern player interactions and decision-making within a game (Phase 3 in the design) such as game format, rules, players, events, scoring, background story and so on (Peters & Westelaken 2014; Ravyse *et al.* 2017).

The multi-actor decision-making context of the urban flooding problem was incorporated by introducing player roles in the game. Two key actor groups for overcoming the current lack of collective action are represented in the game: residents living in monumental houses and the municipality. The challenge as perceived by the municipality is the upgrade of sewers to reduce flooding while balancing the impact on monumental value, costs, and nuisance for residents, whereas for the residents, the key challenge is to select the options they can put on their private property for flood protection and its impacts on other goals such as costs and biodiversity benefits.

Furthermore, from the interviews, it became clear that these groups are not homogenous and that members have different perspectives within each group. For instance, some residents prioritise blue-green areas while others prioritise cost-effectiveness. Similarly, the municipality is composed of multiple departments, each with

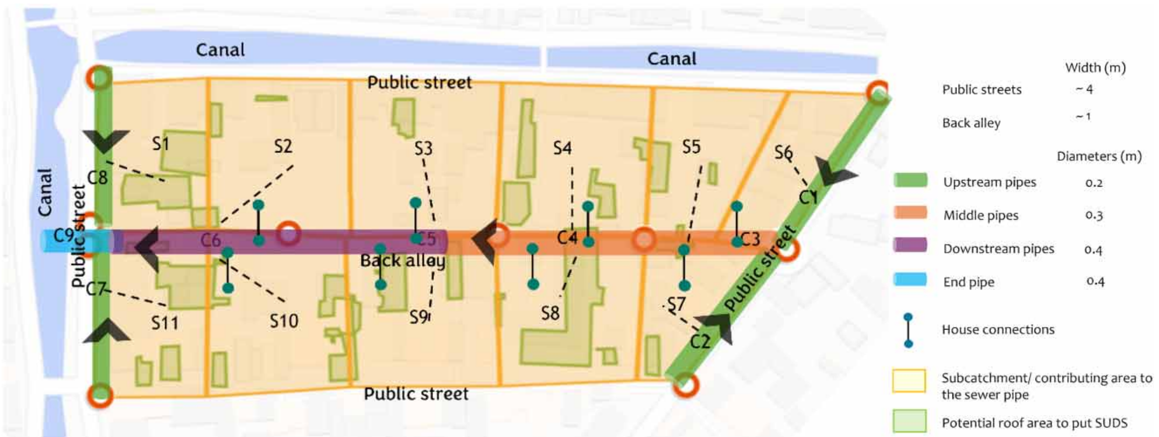

Figure 1 | Base case infrastructure in the case study area.

its own focal objectives such as climate adaptation, protection of monumental heritage, and reduction of flood damage. To account for this, each player was, in addition to the player roles, given an individual focal objective.

To ensure that players not only learn about the impact of solutions at the individual or (actor) group level but also at the collective level, all players were given a collective objective. Furthermore, to make players realise the interdependencies between the two groups, rounds were designed to segregate the two groups initially – residents and municipality. This was done to ensure that players can first explore their own part of the overall system and gradually move on to collective decision-making where they are exposed to the perspective of the other actor group.

To make players appreciate various performance trade-offs in combining blue, green, and grey solutions, a simplified Excel computation sheet with a simple user interface (UI) was designed for players to enter their choices and get feedback. The indicators to assess the choices of the players primarily focused on key issues in the case study area: different types of costs, nuisance, flood damage, and benefits of SUDS. In addition to water storage, the percentage of blue-green area added was used as a proxy indicator for resulting co-benefits from SUDS such as biodiversity, water quality, air quality, soil management, and heat island effect. This choice was made with the intention to keep the number of indicators manageable and avoid cognitive overload. Lastly, to test the game with more players, the game was conducted in a tournament-style session, wherein players were divided into teams that competed to find the 'best' solution.

2.3. Decision-support tool

2.3.1. Components of the tool

The backbone of the Urban Drain game is an Excel-based decision-support tool composed of three separate sheets: 'Round 1 Municipality', 'Round 1 Resident', and 'Round 2 Collective' (see the Supplementary material B for pictures). The first two sheets are focused on the first phase of the game where the municipality and residents look independently from each other at sewer system options and SUDS, while the third sheet is focused on developing a collective stormwater management solution in the second phase of the game.

Considering the sewer infrastructure, two options are included in the Urban dRain game: (1) Existing sewer system upgrade: upgrading the existing infrastructure by increasing the diameters of the pipes to create more network storage (Figure 1) and (2) New sewer system design: decommissioning the existing system and laying down new pipes in the public streets in front of all houses (see Figure 2). For both options, a pre-decided layout was used wherein the pipes were divided into four categories: upstream, middle, downstream, and end pipe. In the game, players could choose one of the two above options and decide on the pipe size for each category.

Due to the lack of space in the public area, only private area was considered available to implement SUDS. Players could choose the percentage of total available roof, garden or wall space to be covered with SUDS. To assess the performance of the sewer layout and SUDS options, several indicators were used (Table 1). Data to calculate these indicators was collected from multiple sources. The rainfall data and cost details for sewer pipes were taken from RIONED – a Dutch knowledge base on urban water infrastructure topics (RIONED 2019a, b, 2020, 2021). The data for existing sewer infrastructure in the case study area including pipe diameters

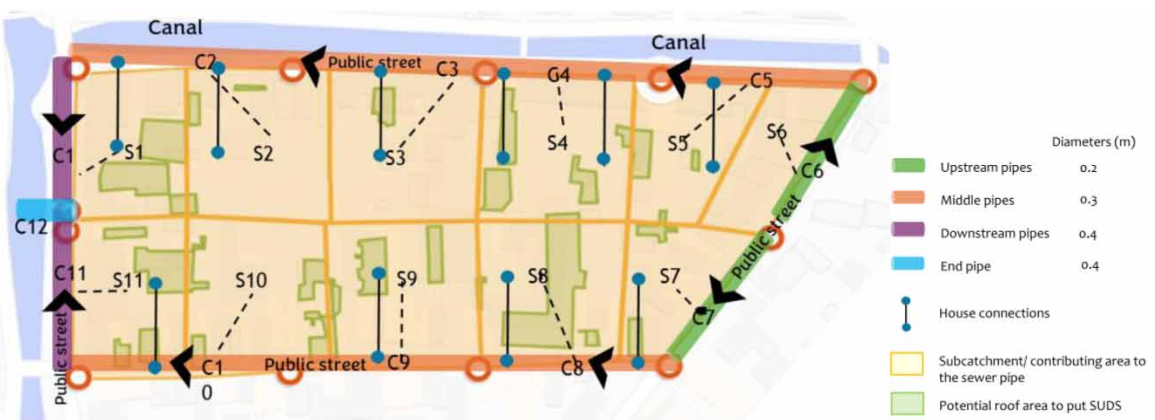

Figure 2 | Second option for the layout for putting new pipes in the public street.

Table 1 | Performance indicators to evaluate sewer and SUDS options (see the Supplementary material B.3 and B.4 for details about the underlying data and methodology used for calculation)

Indicators	Units	Assessment
Sewer options		
Investment cost	Euros	The one-off cost of laying down new pipes in the sewer system. Includes material costs and labour costs
Operation and maintenance cost	Euros	Cumulative maintenance costs for high-pressure cleaning of the pipes until the year 2050 assuming new pipes do not require maintenance catchments
Flood damage	Euros	Total damage cost due to flooding (calculated from flooding depths across all individual sub-catchments)
Additional cost to connect houses to the sewer system	Euros	A rough estimation of additional costs for re-piping and laying down new stormwater pipes to connect to the new/upgraded sewer
Monumental value	High, medium, low	Proxy indicator for the heritage value of the neighbourhood
Construction nuisance inside the house	High, medium, low	Proxy indicator for the level of nuisance inside residents' houses resulting from sewer construction work
Blue-green options		
Water storage	m^3	Total volume of water storage provided by the implemented blue-green measures
Flood damage	Euros	Summation of the damage costs corresponding to flooding depth across all individual sub-catchments
Investment cost	Euros	One-off cost for implementing SUDS including material and labour costs
Maintenance cost	Euros	Cumulative maintenance costs for SUDS until 2050
% of the blue-green area added	–	The ratio of added green and blue-green areas compared to the total grey area that can be potentially covered with SUDS

is sourced from an engineering consulting company involved in pilot projects in the case study area. Data for SUDS such as typical size, costs and water storage capacity was gathered from multiple sources: results on pilot projects (Pötz & Bleuzé 2022), Climate Resilient City tool (Brolsma 2024; Deltares n.d.), websites of providers who design and sell SUDS products (Enduramaxx n.d.; Hornbach n.d.) and studies that assess the effectiveness of specific SUDS measures (Perini & Rosasco 2013; Kew *et al.* 2014). Wherever precise data were not available, an estimate was made by the authors (see the Supplementary material B for detailed calculations).

2.3.2. Hydraulic modelling of sewer options and SUDS

A simplified 1D hydraulic model of the current system was made in the Excel spreadsheet. The study area was divided into 11 sub-catchments, each with a corresponding area (A_i) and an average runoff coefficient (C_i) deduced from the density of infrastructure type from the Google map images of the sub-catchment. Each of the sub-catchments discharges into a singular node, and the peak runoff is calculated through the Rational method (Kuichling 1889; Lloyd-Davies 1906; Butler & Davies 2004). The peak inflow at the downstream end of the whole area can be calculated using this method as follows:

$$Q_{\text{in}} = i_{\max} \cdot \sum_{i=1}^{11} C_i \cdot A_i \qquad (1)$$

where $i_{\max}$ is the peak rainfall intensity. To dimension the sewer system (i.e. pipes) in the base case, a standard rain shower derived from historical rainfall in the Netherlands (RIONED 2019a, b) with a peak of 39.6 mm/h and return period of two years (typical for the Netherlands) was used. The resulting pipe diameters ensuring no flooding on the ground are shown in Figure 1. To plan for the future, a horizon up to the year 2050 was used considering the high-emission climate scenario. In this scenario, peak rainfall of 78.9 mm/h for a return period of two years was used. Based on the selected sewer system layout option (upgrade or new) and the corresponding upgraded/new pipe diameters provided by the players, the sewer network hydraulic performance was evaluated by calculating the relevant hydraulic grade lines along all flow paths (see the Supplementary material B.2). The resulting flooding depths were calculated by comparing the obtained hydraulic grade lines with the corresponding ground levels. Any flooding depths (identified as total head above the ground level) were converted into flood damage costs using a depth-damage curve (Vogelzang 2023). This was done individually for each sub-catchment by also taking into account the number of houses in each of these (with assumption that if there was flooding in the sub-catchment then all houses were flooded with the same water depth).

SUDS options were modelled by modifying the discharge coefficients (C_i values in Equation (1)) of each sub-catchment (see the Supplementary material B.2). Each sub catchment was divided into public area and private area, and the private area was further divided into roof area, outside residential space area such as backyards and front yards and wall/facade space (see Figure 3). The SUDS chosen by the players were distributed across the sub catchments proportional to the roof, outside, and wall space area in the sub catchment. With implementation of SUDS, the discharge coefficient of the sub catchment would effectively reduce, thereby reducing the runoff inflow into the sewers. As peak outflows were considered only, storage capacity increase through SUDS was not explicitly modelled but implicitly included via decreased discharge coefficients and the corresponding inflows.

2.4. Game concept validation and evaluation

To validate and test the impact of the game, four play test sessions were organized. A summary of the sessions and the iterative development of the game is presented in Table 2. The first two sessions were focused on testing the prototype gameplay and removing major errors and the last two were focused on testing the impact of the prototype. Informed consent procedures were followed to collect data and comply with privacy and European General Data Protection Regulation norms. These were approved by the TU Delft Human Research Ethics Committee (approval no. 3287).

2.4.1. Game iterations and play-test sessions

The initial concept of the Urban dRain game revolved around finding a collective solution wherein the municipality and residents were challenged to find a complete solution combining blue, green, and grey solutions in

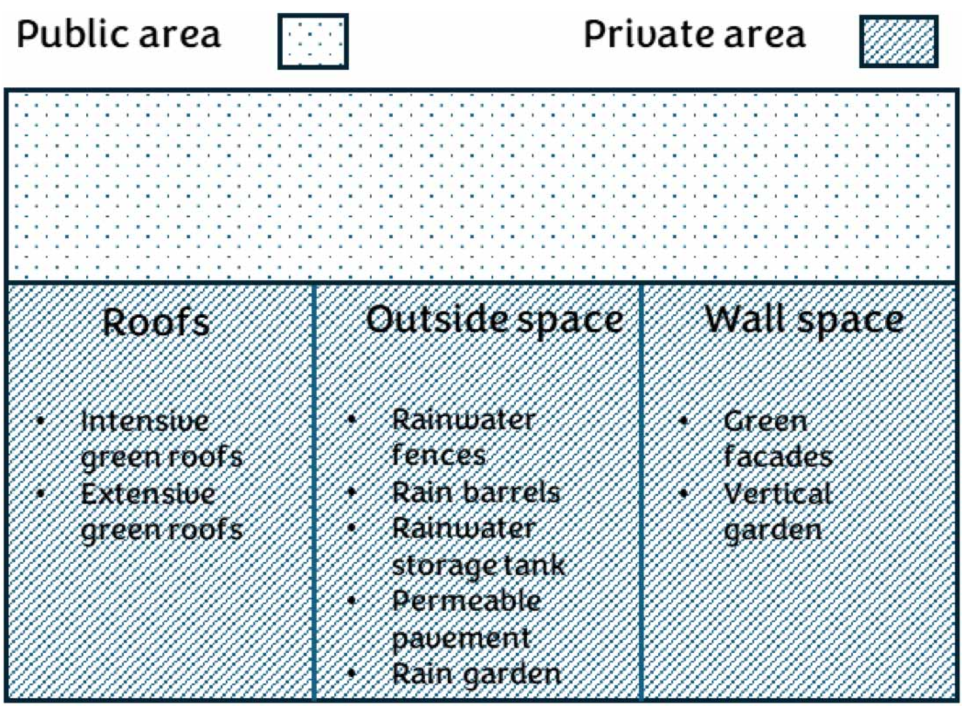

Figure 3 | Division of available private area per sub-catchment and corresponding SUDS to be implemented in the game.

Table 2 | Overview of iterative game development and test and validation sessions conducted

Timeline	Description	Number of players	Key changes made leading up to the session compared to the previous session
6th June 2024	Internal play-testing of the prototype with PhD researchers	4	–
12th June 2024	Play-testing advanced prototype at the International Conference of Urban Drainage Followed by iterations within the project team.	11	• Improvements in Excel UI – adding traffic light colours for indicators to show whether they are desirable or not • Incorporating game manual into introduction presentation, simplifying technical language • Added pre- and post-game surveys to test validation materials
24th September 2024	Validation of final Urban dRain game prototype with MSc students	70	• Adding flood damage for residents and linking the implementation of SUDS with the inflow to sewers • Making residents and municipalities only look at options in private and public land in Round 1 (before designing a collective solution in Round 2) • Simplification of Excel layout to reduce cognitive load and make UI more intuitive • Introduction of a group winning criteria
4th October 2024	Post-validation session with researchers to test optimization potential for future versions	7	• Max. limit on available surface area for SUDS • Introduction of acceptable criteria and budget at the individual player level to stimulate more negotiation and discussion • Introduction of rules to pool in budget

Round 1 and improve it in Round 2. This concept was first tested with four PhD researchers in Water Management at TU Delft. This session lasted 1.5 h and focused on the gameplay aspects. Players identified ambiguities and inconsistencies in the Excel sheet and suggested improvements to aid interpretation and understanding. For instance, one player found the interpretation of qualitative indicators such as 'monumental value' unclear, so a traffic light scheme was added, with red indicating undesirable and green indicating desirable outcomes.

The improved serious game prototype was play-tested by 11 participants at the 16th International Conference on Urban Drainage). Eight participants were researchers and three represented Dutch water utilities. This session lasted 2.5 h, incorporating an anonymous pre-game survey, gameplay, and a post-game survey. The game was rated high on aspects of enjoyment and relevance but rated low on 'actions to control the game' and (ability to) 'assess own performance' (see the Supplementary material C). Players' suggestions included enhancing game mechanics by providing a clearer challenge, incentives for collaboration, while resolving deadlocks between the groups. Also, the amount of information in the Excel UI was found to be overwhelming and large group size made its use on a laptop screen challenging. Furthermore, we re-evaluated the use of surveys and opted for a short digital post-game survey and debriefing questions to allow more time for in-depth discussion of experiences and learnings with players (as integral part of the overall game play intervention). The project team used these insights for further iterative adjustments of the game and the validation approach towards a final game prototype.

2.4.2. Validation of the final prototype

Once the identified issues were ironed out iterative improvements led to a mature game, which constituted the final prototype. The main change is that the residents and municipality focus attention only on their part of the system in Round 1 instead of aiming to design the whole solution at once to then iterate on it in Round 2. This version was played validated with 70 first-year students of the MSc programme Engineering and Policy Analysis at TU Delft on 24th September 2024. The students had little to no background knowledge of urban drainage and related issues. Two sessions of Urban dRain were conducted with 35 participants each, one in the morning and one in the afternoon. In each session, players were divided evenly into four teams of 8–9 participants.

A post-game digital questionnaire was deployed to collect feedback on player's learning and gameplay experience (see the Supplementary material D). The questions covered aspects such as player background, overall game rating, goals prioritized, and 7-point Likert scale statements on game experience (Haider *et al.* 2022), learning and awareness towards the goals of the game. The surveys were kept anonymous and no personal information was collected. At the end of the game session, a short plenary discussion on the below questions was held:

- How was it to step into the shoes of the municipality/residents and how can you relate it to the real world?
- Was there anything challenging about the decision-making? How did you go about improving the solution?
- Was there anything remarkable or unexpected that you are taking away from this session?

Forty-nine out of 70 players who played the game filled the post-game survey and the results from these surveys are presented in the Results section.

2.4.3. Post-validation to optimize the final game prototype

The feedback of the validation session highlighted further smaller points by which the final game prototype could be optimized for consideration during future creation of a final, commercial-grade game from the prototype. This included assigning an individual budget and winning criteria to each player rather than the whole group to focus attention and motivation to enhance learning. The changes were play-tested with seven researchers from TU Delft on 4th October 2024 who had not earlier been involved/played the game. The insights from the play-test session are also presented in the Results section.

3. URBAN DRAIN GAME

3.1. Storyline and objective

The Urban dRain session starts with the game facilitator introducing the problem context and the game challenge. Players are welcomed to a fictitious 'FloodCity' and are told that the city centre has been experiencing frequent flooding in the past few years leading to damages and nuisance for the residents. The underground sewer infrastructure of the area is old and in need of an upgrade, also to withstand more intense rain showers in the future. This provides an opportunity to integrate blue-green infrastructure measures. Players are challenged to develop a rainwater management solution for the neighbourhood for the year 2050 by upgrading the sewers or redesigning the sewer system in combination with newly added blue-green solutions. The introductory presentation can be found in the Supplementary material E.

3.2. Game setup and roles

At the start of the game, players within a team are divided into two sub-groups: residents or municipality, with each sub-group consisting of 4–5 players. Players then select a specific role within the sub-group (see Figure 4 for an example of a role card and the Supplementary material F for all role cards). The role cards are already arranged on the table and players can pick the card in front of them. Each role comes with a distinct personal objective, i.e. the player's perspective on what should be prioritised for the collective solution. For instance, a resident may prioritize low nuisance and disruption due to construction work or a municipality official may prioritize minimizing costs for the municipality.

Figure 4 | Example of role cards in the Urban dRain game.

3.3. Rounds and progression

After the setup, the game progresses as shown in Figure 5. Players begin with Round 1, where residents and municipalities explore the solutions on private and public property separately to deal with the issue of flooding and harness co-benefits in the neighbourhood. Both groups are given their own respective budget to implement the solutions (1,000,000 euros for the municipality and 500,000 euros for residents). The municipality representatives look at two sewer options – upgrading the existing sewer in the back alley or implementing a new sewer system in the public streets (see Figures 1 and 2). Meanwhile, the residents look at the SUDS they can implement on private land including roof area, outside space, and wall spaces (see Figure 6). In total, nine solutions that are proven to be effective and are typically used within the specific Dutch urban context are offered. Each group has about 20 min to familiarise themselves with the solutions, input them in their respective Excel sheet, and explore their impacts.

In Round 2, all players come together as one group which has a total budget equivalent to the sum of the resident and municipality budgets, i.e. 1,500,000 Euros. Players have 30 min to repeat the planning exercise. This time, they must collaboratively develop and negotiate the solution using the collective Excel sheet (see Figure 7) and discuss points of disagreement. For this round, they can enter their choices in the collective Excel sheet. Players can either combine blue-green solutions with a new sewer system design or upgrade the existing system. Their challenge for Round 2 is to come up with a solution that at least meets all the below conditions:

- No flood damage;
- The maximum total investment budget;
- Minimum area coverage of 20% with blue-green solutions;
- Agreement on the distribution of costs.

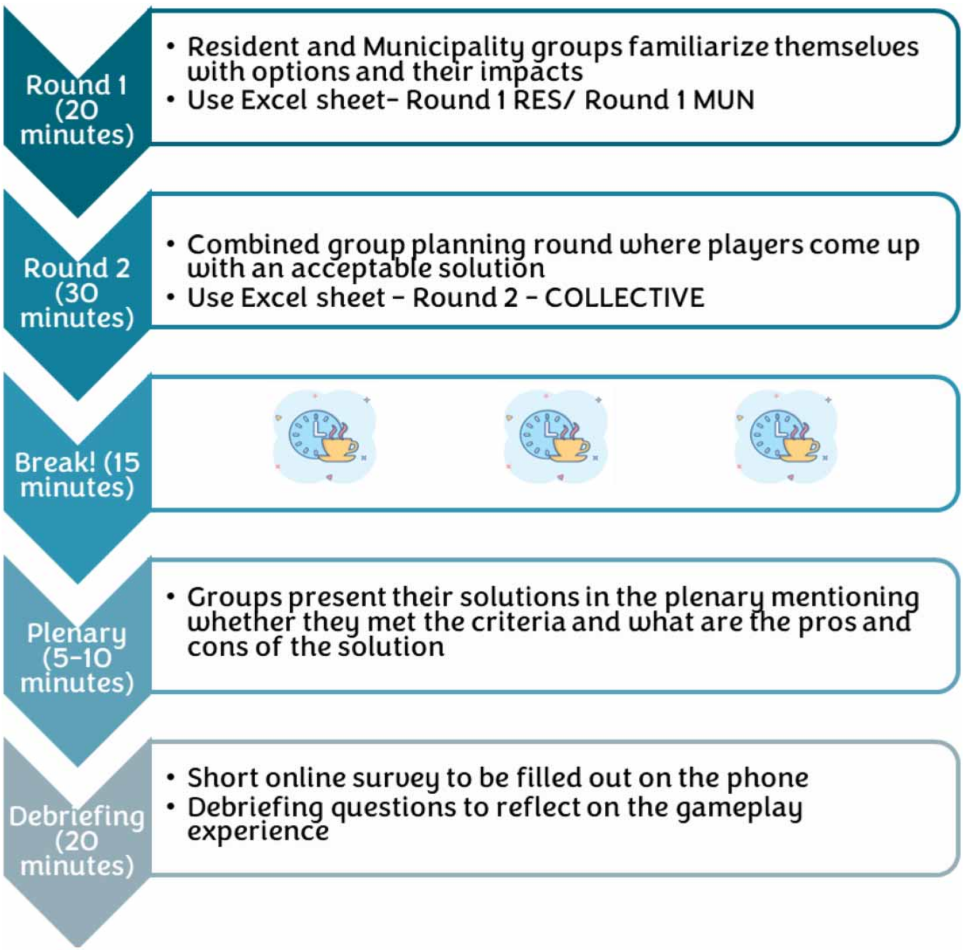

Figure 5 | Progression and round in the Urban dRain game.

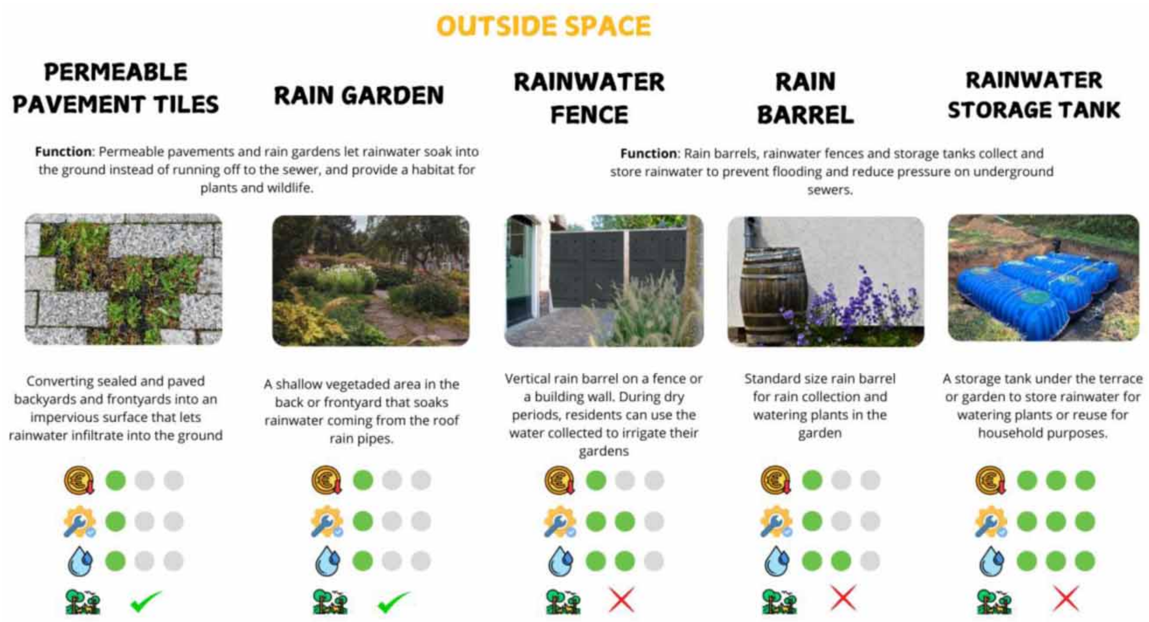

Figure 6 | Example of a blue-green solution card.

Acceptable solution criteria

Max flood damage (x 1000 euros)	Max. total budget (x 1000 euros)		Minimum % of blue-green area added	Agreement on cost distribution b/w municipality and residents
	Residents	500		
	Municipality	1000		
0	Total	1500	20	YES

>> Blue-green solutions + new sewer layout <<

ROOF	**% of roof space**					
Standard sedum roof	0					
Intensive green roof	0					
HOUSEHOLD UNITS	**% of houses**					
1 Rainwater fence	0					
1 Rain barrel	0		**Upstream pipe diameter (m)**	**Middle pipe diameter (m)**	**Downstream pipe diameter (m)**	**End pipe diameter (m)**
1 Rainwater storage tank	0		0.2	0.4	0.45	0.5
OUTSIDE AREAS	**% of outside space**					
Permeable pavement	0					
Rain garden	0					
FACADES	**% of facade space**					
Green facades	0					
Vertical garden	0					

Impacts Total

	Flood damage (x 1000 euros)	Investment costs (x 1000 euros)	Operation & maintenance costs (x 1000 euros)	% of blue-green area added	Monumental value	Construction nuisance (indoors)
Total	19	824	0	0	Low	High
		842				

>> Blue-green solutions + upgrade current sewer layout <<

ROOF	**% of roof space**					
Standard sedum roof	0					
Intensive green roof	0					
HOUSEHOLD UNITS	**% of houses**		**Upstream pipe diameter (m)**	**Middle pipe diameter (m)**	**Downstream pipe diameter (m)**	**End pipe diameter (m)**
1 Rainwater fence	0					
1 Rain barrel	0	Existing system	0.2	0.3	0.4	0.4
1 Rainwater storage tank	0	Upgraded system	0.2	0.45	0.5	0.4
OUTSIDE AREAS	**% of outside space**					
Permeable pavement	50					
Rain garden	5					
FACADES	**% of facade space**					
Green facades	0					
Vertical garden	0					

Impacts Total

	Flood damage (x 1000 euros)	Investment costs (x 1000 euros)	Operation & maintenance costs (x 1000 euros)	% of blue-green area added	Monumental value	Construction nuisance (indoors)
Total	0	907	35	20	High	Low
		942				

Figure 7 | Collective Excel sheet to support decision-making in Round 2.

The last point, how the municipality and resident players should come up with an agreement on the cost distribution, was kept open-ended to allow for player discussion and creativity in potential funding mechanisms, e.g. use of subsidies, taxes, one-off investments. For the final solution, players could select what percentage of each cost type, e.g. investment and maintenance costs of SUDS and sewers, would be covered by the municipality and the resident. At the end of Round 2, the group is asked to present their solution, and the winner(s) are selected based on the criteria above.

In case of a tie, teams that achieved the largest implementation of the blue-green area (with the other three criteria still holding) are declared the winner. The game concludes with participants filling out the post-game survey and a brief plenary discussion of their gameplay experience.

4. GAMEPLAY RESULTS

Figure 8 (left) shows the gameplay session in action. Overall the final game prototype rated at 3.55 out of a maximum of 5 points. The game was further evaluated on aspects of learning and player experience. In this section, we present the results from the game sessions, survey data, and debriefing sessions. Detailed responses to the survey questions can be found in the Supplementary material G.

4.1. Solution strategies

All teams achieved zero flood damage. Budgets ranged from €942,000 to €1,493,000, with higher expenditures correlating to larger areas covered by blue-green infrastructure. Since all teams were able to achieve the minimum winning condition for the game, the winner was declared based on the maximum blue-green area achieved by the collective solution.

Seven out of eight teams chose the upgrade sewer option, increasing the size of the middle and downstream pipes to a higher diameter, reflecting an emphasis on increasing capacity to handle larger stormwater volumes. This option required relatively lower investments for sewer upgrades, leaving the remaining budget to increase the coverage of the blue-green area. The winning teams, Groups 4 and 7, strategically integrated sewer upgrades with SUDS. Group 4 increased the middle (0.3 m → 0.4 m) and downstream pipe sizes (0.4 m → 0.5 m), complemented by permeable pavements (50% of the outside space) and rain gardens (20% of outside space), achieving a significant blue-green solution coverage of 42% of the total private area available for implementing SUDS. Group 7 did modest sewer upgrades (middle pipe to 0.35 m and downstream pipe to 0.5 m) and invested heavily in SUDS, achieving the highest blue-green area (47%) through sedum roofs and permeable pavements. Teams 6 and 8 opted for smaller pipe upgrades (0.3–0.4 or 0.45 m). They had lower budgets (e.g., €1,139,000 for Group 8) but still maintained zero flood damage and moderate blue-green areas.

Unlike other teams, team 3 chose the new sewer system wherein new pipes would be laid in the front public street of the neighbourhood. This required the highest budget (€1,491,000) and added 26% blue-green area. While expensive, the group focused on making a neighbourhood for the future, one they argued would be resilient and reduce flood damage as long as the additional cost incurred by the residents to connect to the front sewer is covered by the municipality.

Since the municipality had a bigger budget, the investment and maintenance costs of sewers were covered fully by the municipality in seven out of eight teams. Team 7 adopted an equitable cost-sharing model, where both municipality and residents contributed proportionately across all cost categories (67% MUN, 33% RES), promoting shared responsibility for both sewers and SUDS between public and private actors. Depending on the sewer layout chosen, other teams followed two strategies to share financial costs for investment and maintenance of

Figure 8 | Game play sessions in action (left – game session with 70 MSc. students and right – testing the last iteration of the game concept).

SUDS and the re-piping costs to connect to the sewer layout. In teams 1, 4, and 5, the municipality took on a portion of the SUDS investment or maintenance costs in addition to the sewer costs. In team 3, which laid a new sewer in the public street, an agreement was made where the municipality would also cover the re-piping costs that would otherwise be paid by the residents and a part of the investment costs (~30%) for SUDS. Teams 2, 6, and 8 followed a similar strategy where the municipality fully funded sewer upgrades, while residents assumed all costs related to SUDS and re-piping. This division created a clear separation between public infrastructure and private green investment reflecting the current distribution of responsibilities. The variety of solutions that came from the teams indicates that the technical design aspect of the game was realistic and well-catered to the case study.

4.2. Player experience

Overall player experience after the game was largely positive, taking into account players who ‘somewhat agreed’, ‘agreed’, or ‘strongly agreed’ with the statements. Approximately 70% of the players found the game to be relevant, 84% of the players had a good time playing the game and 76% of the players felt that they were good at playing the game (Figure 9).

Taking into account players who ‘somewhat disagreed’, ‘disagreed’, or ‘strongly disagreed’ with the statement, some aspects of the game were rated low. For instance, 41% of the players felt that the actions to control the game were not clear to them, which largely relates to the ease of use of the Excel interface. Participants mentioned it being ‘unclear’, ‘not working’, or ‘messy’ to use for effective gameplay or optimisation. One key error that some players pointed out during the session was that implementing lots of SUDS options in the outside space increased flooding rather than decreasing it. This was because there was no constraint equal to the available space in the sheet, leading players to effectively create more surface area by implementing a lot of SUDS, thereby creating more inflow to the sewers (resulting in more flooding).

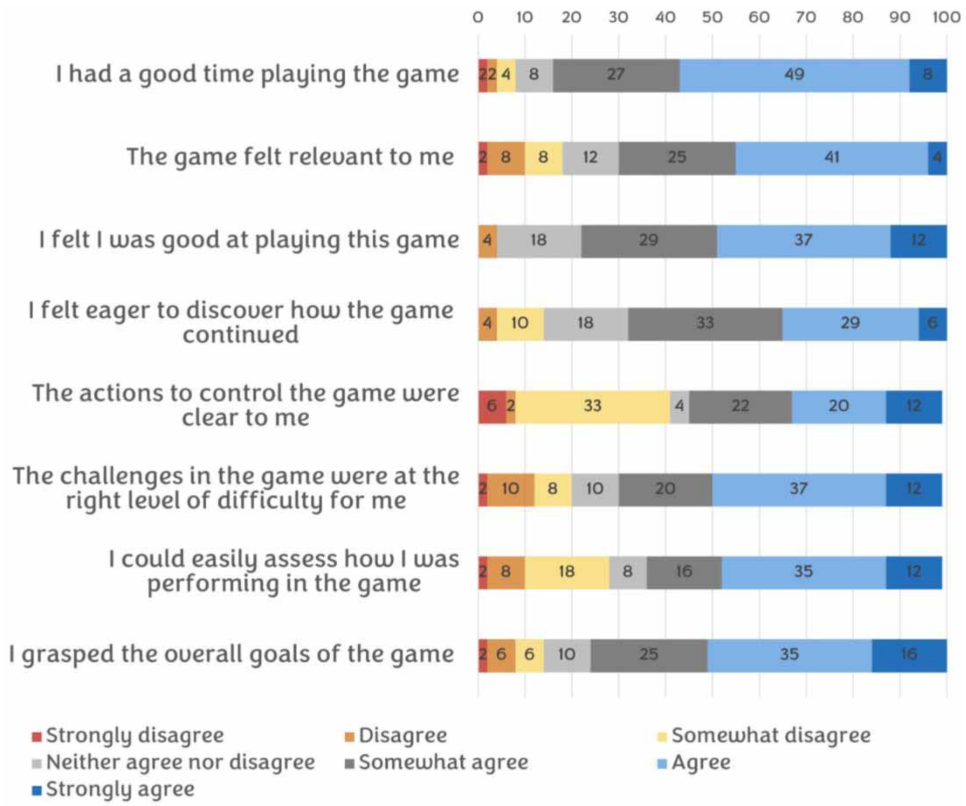

Figure 9 | Responses to Likert-scale questions related to game experience in the post-game survey ($n = 49$). Percentages have been rounded to the nearest integer.

Approximately 20% of the players felt that the challenges in the game were not at the right level of difficulty. One player mentioned that 'it was quite fun but I missed the challenge in the game' and another stated 'I feel like the case could be more challenging and fun by making the requirements harder to reach'. Approximately 28% of the players struggled with assessing how they performed in the game and noted that the scoring system made it easy to satisfy the winning conditions (given overall high budget). Some game choices were perceived as unclear (like whether players would be rewarded for saving some budget) or overly focused on blue-green area creation instead of weighing in on other goals players may have. Despite this, players appreciated the potential for simulating real-world government-resident interactions and engaging with the process of budget allocation beyond development of a technical solution only.

On aspects of game design mechanisms and elements, some players suggested that the game felt more like an assignment rather than a playful, interactive experience, suggesting a misalignment in the expectations from a game. One participant noted 'It didn't really feel like a game, more like a study assignment. A fun assignment!' and another mentioned 'I like the idea, but it would be nice to have actual boards with information (like board game material) instead of loose papers'.

4.3. Learning and awareness

Figure 10 shows the responses to the survey questions on learning and awareness. Overall, these are high, albeit with a broad range of opinions between participants and specific aspects. The results indicate that the game was particularly effective, with 80% of players reporting increased awareness of urban flooding context, 85% acknowledging a greater sense of shared responsibility, and 79% feeling motivated to engage in collective problem-solving. Players mentioned they had 'fun and learned a lot about the collaborative aspects with residents', that 'it was interesting to see what parameters changed the outcome…and when the two parties came together', indicating learning on both technical and social goals.

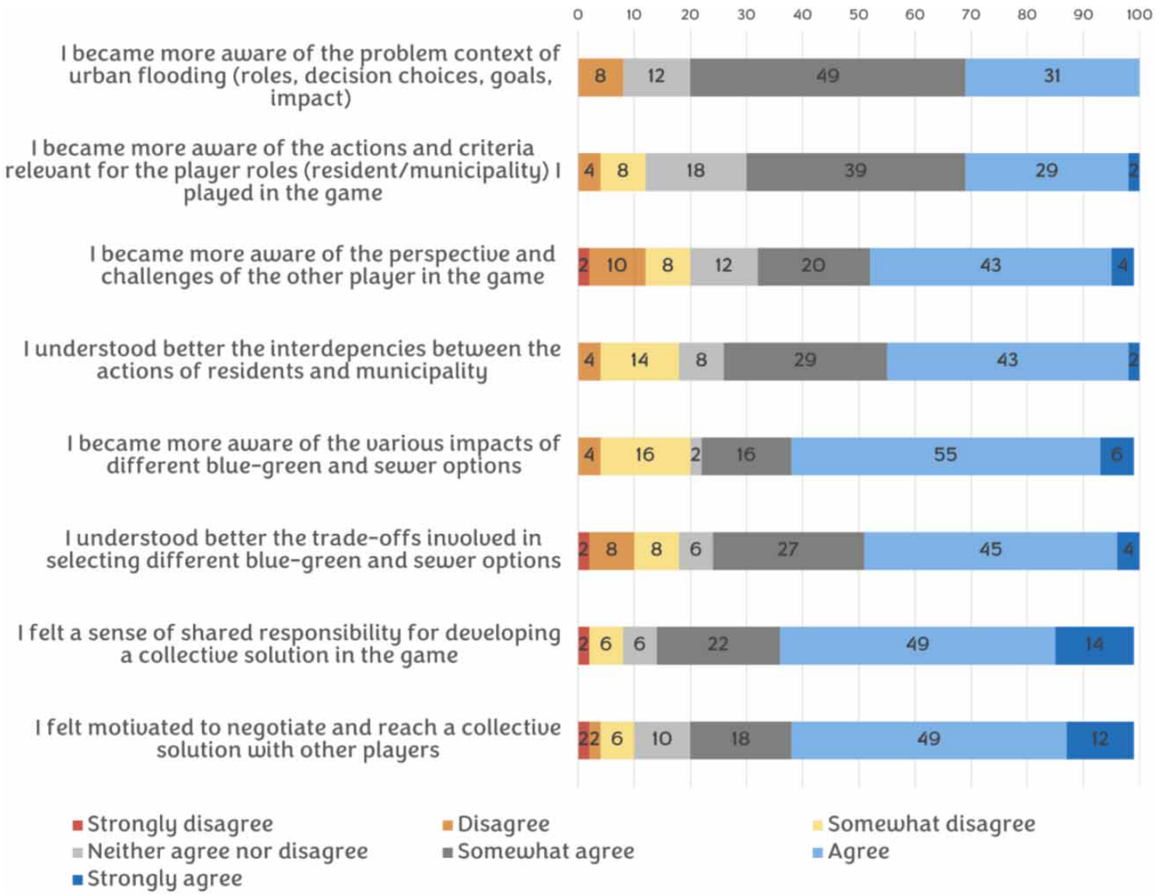

Figure 10 | Responses to Likert-scale questions related to learning and awareness in the post-game survey ($n = 49$). Percentages have been rounded to the nearest integer.

Conversely, 20% of players expressed some level of disagreement regarding the game's effectiveness in helping them understand other players' perspectives and challenges. In the debriefing discussion, players mentioned that they could not get into the skin of the roles they were assigned and recommended revisiting the criteria to win the game. They suggested using voting to decide the winner or assigning individual budgets to the players rather than a collective budget. This would stimulate more negotiation among the players to pool in their budget. The team size might have also played a role in hampering discussions and negotiations. One player mentioned that 'There were more players on our team, which meant that there were more citizens with the same role. This made negotiations harder.' Similarly, 20% of respondents (somewhat/strongly) disagreed with the statement about 'becoming more aware of the impacts of blue-green and sewer options'. This implies that players either already knew about the impacts of these options or did not learn anything new.

4.4. Optimizing the final game prototype

Based on the feedback received from the session with 70 students, we explored optimization potential by implementing some of the suggestions that would further align the play session process with the social and technical goals of the game. Firstly, in the Excel sheet, players could see how much space they had already covered with SUDS and were given a warning if they exceeded the total space. Secondly, the overall goal was kept generic – finding a collective solution within the available budget that reduces flood damage while adding incentives at the individual level to increase negotiation and discussions. Players were provided with more detailed backstories and individual goals. For instance, a resident living on the top floor of a building aims to add an additional 20% of blue-green area while the civil engineer from the municipality wants to ensure zero flood damage. Additionally, the overall budget was split into individual budgets that players could contribute if they were happy with the overall solution. Moreover, competition was within the group itself, with players who achieved their individual goals declared as winners. The updated game introduction presentation, role cards, and Excel sheet images can be found in the Supplementary material H. The seven TU Delft researchers who assisted with post-validation gave it an overall rating of 4.3 (see Figure 8 – right and see the Supplementary material H for detailed results), relatively higher than the rating on the previous iteration (however, the different sample size and characteristics do not allow deriving significant conclusions from this). Participants found the game to be 'interesting and fun' and the group dynamics were praised for fostering an 'interactive and competent environment.' Aspects related to the Excel UI and learning were rated well.

5. DISCUSSION

5.1. Game playing results

Reflecting back on the meaning and purpose of the Urban dRain game, it set out to integrate the technical assessment of urban drainage solutions to combat urban flooding with actor negotiations through the medium of a serious game. The game was successful in stimulating players to undergo a process of trial and error learning and improve upon their solutions to meet the minimum winning criteria. This is also observed in similar games developed on water distribution and flood mitigation problems such as SeGWADE (Morley *et al.* 2017) and the Millbrook serious game (Khoury *et al.* 2018). As executed in SeGWADE, the intermediate solutions entered into the Excel sheets can be recorded in the future gameplay sessions to better understand the trajectory of achieving the final solution. In the context of learning models (Lozano 2014; Gugerell & Zuidema 2017), the game contributes to single loop learning as players were able to make adjustments and corrections to the combination of solutions. Achieving higher levels of learning (double and triple loop) would require facilitation of discussions on underlying assumptions and values. For instance, players could be nudged to reflect on how to value indicators such as nuisance and monumental value, or propose other indicators they deem necessary to include in a specific real-world situation (such as long-term resilience, access of sewers, or property rights).

In terms of learning about social goals, the game was successful in initiating discussions among teams representing different actors and their varying perspectives. The results align with findings from other serious games where it was found that game interventions led to an appreciation of other actors' interests and facilitation of a collaborative environment (Poplin 2012; Marome *et al.* 2021; Delaney 2022; McConville *et al.* 2023). A role-playing game is considered effective for stepping into the shoes of the assigned actor, embody their goals and intentions, and surface potential conflicts (Gurung *et al.* 2006). The 'Kin Dee You Dee' game (Marome *et al.* 2021) highlighted the issue of groupthink as a concern in implementing group-based serious games. This was not explicitly monitored during the implementation of Urban dRain. Future work could seek to monitor the occurrence of groupthink and seek to employ proven methods to reduce it in group settings (Sunstein & Hastie 2015).

While the Urban dRain game supports collaborative urban drainage design, it may present an idealized version of the process. Given the limited solutions available in the game and the generous budgets, we did not encounter major conflicts during gameplay. However, conflicts may arise when the game is applied in real-world stakeholder settings (Medema *et al.* 2016; Keijser *et al.* 2018; Bekius & Gomes 2023). To address such situations, prior preparation is necessary to manage disputes effectively and integrate them into the debriefing process. One possible approach is to introduce flashcards with guiding questions that facilitate discussions between participants. For example, the flashcards could prompt actors to identify areas of agreement, examine the root causes of disagreements – whether they stem from a lack of solutions, missing criteria, or concerns about fairness – and explore ways to resolve these conflicts. The outcomes of these discussions can help guide next steps after the game sessions, such as conducting further research, performing additional analysis, or developing innovative solutions beyond the scope of the game.

The results also reveal that it is difficult to maintain a balance between the social and technical goals of the game. We adjusted the game mechanics through multiple iterations to improve this balance. We observed that in a tournament-style setup (Wang & Davies 2015; Teague *et al.* 2021; Khoury *et al.* 2023) where winning criteria were provided to teams, actor negotiations were limited as players quickly dropped their individual goals and focused on winning by achieving a good technical solution to meet the winning conditions. However, through game optimization as described in Section 4.4, this can be overcome by framing the competition as one within the group as players were more motivated to reach their individual goals. It seems that playing the game in tournaments overemphasizes competition, and a collaborative-competitive game setup (Buchinger & da Silva Hounsell 2018) works better. Playing the game in single groups where players need to find a minimum viable solution at the collective level to qualify while still trying to achieve individual goals might be a good strategy to nudge both technical and social learning.

5.2. Further improvements

Coming to aspects of balancing reality and play in the Urban dRain game, there is scope for further improvement. The underlying hydraulic model to assess the technology options was simplified to make the game playable with minimal computational support and software development requirements. However, the model is limited in the accuracy of the assessment as it does not incorporate pipe-filling dynamics and changing rainfall intensity, which could lead to overestimation of flood damage. Whereas for the sake of this game and the learning, this is appropriate, a planning tournament that aims for an implementable solution in the real world would require more realism by linking the game with a detailed hydrodynamic model in EPA SWMM and using a continuous rainfall dataset instead of design-storms as in this work. Similarly, more accurate estimates for the performance of SUDS could be developed based on local conditions, and detailed financing mechanisms could be added to deepen discussions. The assessment of solutions can be further expanded by considering other goals and indicators to help understand the consequences of solutions, as deemed relevant in the specific context and by the involved actors. For example, aspects of groundwater and surface water interactions for sewers and environmental indicators to assess the impact of SUDS (e.g. biodiversity, water quality, air quality, soil management, and heat island effects) can be further added (Nature4Cities 2016). Adding these additional details could also help boost (relatively low) awareness levels about impacts of SUDS and sewer options as noted in Section 4.3.

The incorporation of ordinal scales for indicators related to nuisance or monumental value is intuitive, yet lacks precision as to different interpretations of what these levels mean in the real world. Instead, interval scales could be constructed to better differentiate between levels on these indicators (e.g. loud noise for a period of x weeks) such that they can be interpreted more unambiguously and evaluated within the winning condition. Furthermore, there are interactions between indicators, which were not considered in the game but can be incorporated to add more realism. For instance, flood damage in the neighbourhood may decrease monumental value, or implementation of SUDS can potentially increase the monumental value of the neighbourhood.

To improve the playability of the game, the creative design and the look and feel of the game could be improved further. Instead of providing layout and SUDS options as loose sheets to players, a dedicated game board can be developed with the map of the area printed on a large board with the current infrastructure implemented as overground pipes/straws, which could be changed by the players. Similarly, SUDS options can also be visualized as game tiles that can be placed on the map and these choices can be entered in the Excel sheet.

Enhancing the game's interface and user interaction is another area for improvement. Some players would have liked a more challenging game and better user interaction with the underlying Excel tool. Similar concerns are raised in other hybrid serious games such as the Millbrook game (Khoury *et al.* 2018) and further simplification of game elements is recommended. Future game sessions could use bigger screens for displaying the Excel sheet to make experimentation more seamless. Additionally, developing a dedicated software or a simplified (online) app that players can use on their phone to replace the Excel interface could provide a more engaging experience. Additionally, team size and the resulting interaction with the Excel sheet could be another factor to improve on.

5.3. Generalizability and further testing with actors

The challenge of upgrading old, urban, and dense city centres is not unique to the case study area but one which is common across the Netherlands and worldwide. Any densely urbanised city with a sizable prevailing architectural heritage and degrading sewer infrastructure that needs replacement can face this issue. In this context, we believe the *Urban dRain* serious game concept could be generalized to address similar situations in other cities, particularly for supporting collective approaches to upgrading urban drainage infrastructure.

To apply the game to a case study with a regulatory and infrastructure context different from the Netherlands, the content of the game would require significant re-adjustments. To aid this, a quick problem analysis should be done using the following guiding questions (see also Mittal *et al.* 2024):

- Who are the key actors, and what are their actions and goals?
- Is there enough awareness among actors about urban drainage issues?
- How is the space divided between public and private areas in the neighbourhood? Are there any other limitations, like historic buildings, that might restrict certain solutions?
- What solutions can be realistically implemented in the case study considering local geographical conditions and groundwater levels?

Mapping the actors in the new context through scoping interviews is key to getting the basic elements of the game in place – actors, their goals, actions, and perceived interdependencies. It is also important to check the base level of awareness about urban drainage issues among the actors engaged in this problem before using this game in an intervention. If the awareness levels are low, especially among residents, consider playing serious games developed for raising awareness on urban flooding and blue-green solutions such as SUDSbury (Nguyen *et al.* 2024) and Where We Move (Arevalo *et al.* 2024) prior to the Urban dRain game. Lastly, the solutions included in the game can be updated based on the local conditions of the case. For instance, if there is enough public space, the list of blue-green solutions can be expanded to include SUDS such as bio-swales and wetlands.

To generalize the game to other cities in the Netherlands, the scope of the game could be expanded to involve other actors such as the water board, water utilities, or environmental agencies in the Netherlands. In the Urban dRain game, we assumed that decisions by these actors would not change in the near future and are generally taken at a larger scale compared to the neighbourhood scale considered in our game. However, if their actions and perspectives are critical, the game can be expanded to include these groups in Round 1 for a more comprehensive discussion.

Although the Urban dRain is designed to support real-world decision-making, it could only be evaluated and tested with students and researchers. Further testing of the game with real-world actors is required to determine its usefulness for practitioners and the general public. Co-developing collective solutions should have multiple advantages for municipalities: initiating public participation, increasing the legitimacy of the measures they implement, gaining local knowledge and a better understanding of public preferences, and advancing principles of fairness and justice (Innes & Booher 2004). However, doing so outside an academic context remains a challenge, as it requires the commitment and active participation of multiple actors. Indeed, playing the game was perceived in our case as a substantial time investment and there was scepticism about the impact of the game to be incorporated within the project meetings that were already planned between the municipality and residents. As a consequence, playing the game with real actors was not possible.

The above is not really a surprise as multiple barriers to the adoption of serious games in practice have been identified before (Ampatzidou *et al.* 2018), including lack of trust or unfamiliarity with gaming as a method and hesitation of incorporating a new tool into the planning process (Billger *et al.* 2017). Possible ways of overcoming these roadblocks are to explain the benefits of using a serious game to all relevant actors and plan together how and when the serious game will be used in the overall decision-making process, for instance, at the early stages of a pilot project to bring relevant actors together and discuss/brainstorm initial solutions. Second, relevant actors can be involved in co-designing the game to create more ownership of the game as an outcome (Roux *et al.* 2017; McConville *et al.* 2023). Lastly, to overcome resource constraints and hesitance towards serious games, mini-games can be developed to reduce time investment (De Jans *et al.* 2017; Ampatzidou *et al.* 2018; Arnab *et al.* 2021). For instance, only one round of Urban dRain can be played at the start of a citizen engagement meeting to introduce the problem and possible solutions which can be followed up with a conventional group discussion.

The game can be played in two formats depending on the audience: a competitive tournament style for large groups or a competitive-collaborative approach within a single group. Our findings suggest that while the tournament format may reduce social learning, the single-group approach supports deeper learning on both technical and social aspects. Since the current version of the game includes seven player roles (four residents and three municipal representatives), it can accommodate seven participants per session, with an option to extend capacity by allowing two players to share a role. To ensure effective facilitation, the facilitator-to-participant ratio should be carefully considered. For large groups, participants can be divided into smaller teams of 7–8, with one facilitator assigned to every two groups. However, for sessions involving real-world stakeholders, we recommend playing in a single group of 7–8 participants to foster richer discussions. At least two facilitators should be present – one to guide gameplay and another to observe and lead the debriefing (Powers & Kirkpatrick 2013). This division of tasks can help manage the cognitive and logistical demands of facilitation.

6. CONCLUSIONS

Platforms that effectively integrate both technical assessment and actor negotiation in addressing urban pluvial flooding issues are missing. To bridge this gap, we present a serious game, Urban dRain, inspired by a Dutch case study that experiences frequent flooding. The game was designed to evaluate the impacts of potential solutions at both individual and collective levels while emphasizing the trade-offs involved in combining blue, green, and grey infrastructure solutions. An Excel-based simplified decision-support tool, incorporating a hydraulic analysis of the sewer network, was employed to assess the impacts of different strategies. Beyond technical goals, the game also aimed to increase awareness of the multi-actor decision-making process and foster an understanding of the interdependence and collective responsibility required to address urban flooding. The game was developed in an iterative manner and play-tested with 70 MSc students and seven researchers. Based on the results obtained the following can be concluded:

- The Urban dRain game provides an effective means of bringing together actors with different backgrounds and potentially conflicting views to co-develop a collective solution for stormwater management in a given neighbourhood area;
- The game supports technical learning by encouraging players to find a cost-effective solution that avoids flooding and maximises coverage of the blue-green area. Integrating all solutions within one underlying hydraulic model can increase the understanding of all actors of the effect they can have on pluvial flood risk in their area;
- The game supports social learning by stimulating them to achieve a collective goal while negotiating also in their own personal interest. Integrating different roles is a key step to improving social learning within a socio-technical serious game;
- A better balance between the social and technical learning goals needs to be achieved via the game design mechanics. A tournament-style game with an overall collective goal and specific individual goals has the potential to achieve that. Improvement of this balance should be sought through further iterations of the game.

Several lines of improvement on the game could be made based on the feedback from the last iterations. The explicit integration of co-benefits associated with SUDSs within the scoring system of the game and improving the accuracy of flood assessments. To deepen learning, future adaptations of the game should include more detailed SUDS options, financing mechanisms, and precise indicator scales. Finally, broader testing with real-world stakeholders is essential to assess the game's practical relevance, requiring strategies to overcome adoption barriers such as co-design approaches, reduced gameplay time, and embedding the game into existing planning processes.

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AUTHOR CONTRIBUTIONS

A.M. conceptualized the work, developed the methodology, rendered support in formal analysis, provided the software, investigated the project, wrote the original draft, wrote and reviewed and edited the article, visualized the work, rendered support in project administration. J.v.d.W. developed the methodology, provided the software, wrote and reviewed and edited the article. L.S. conceptualized the work, developed the methodology, investigated the projects, wrote and reviewed and edited the article, supervised the study, rendered support in funding acquisition. Z.K. conceptualized the work, developed the methodology, wrote and reviewed and edited the article, supervised the project, developed the resources, rendered support in funding acquisition.

DATA AVAILABILITY STATEMENT

All relevant data are available from an online repository or repositories: https://doi.org/10.4121/c9809653-1328-40aa-87e1-f03508fea2fe.v2.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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