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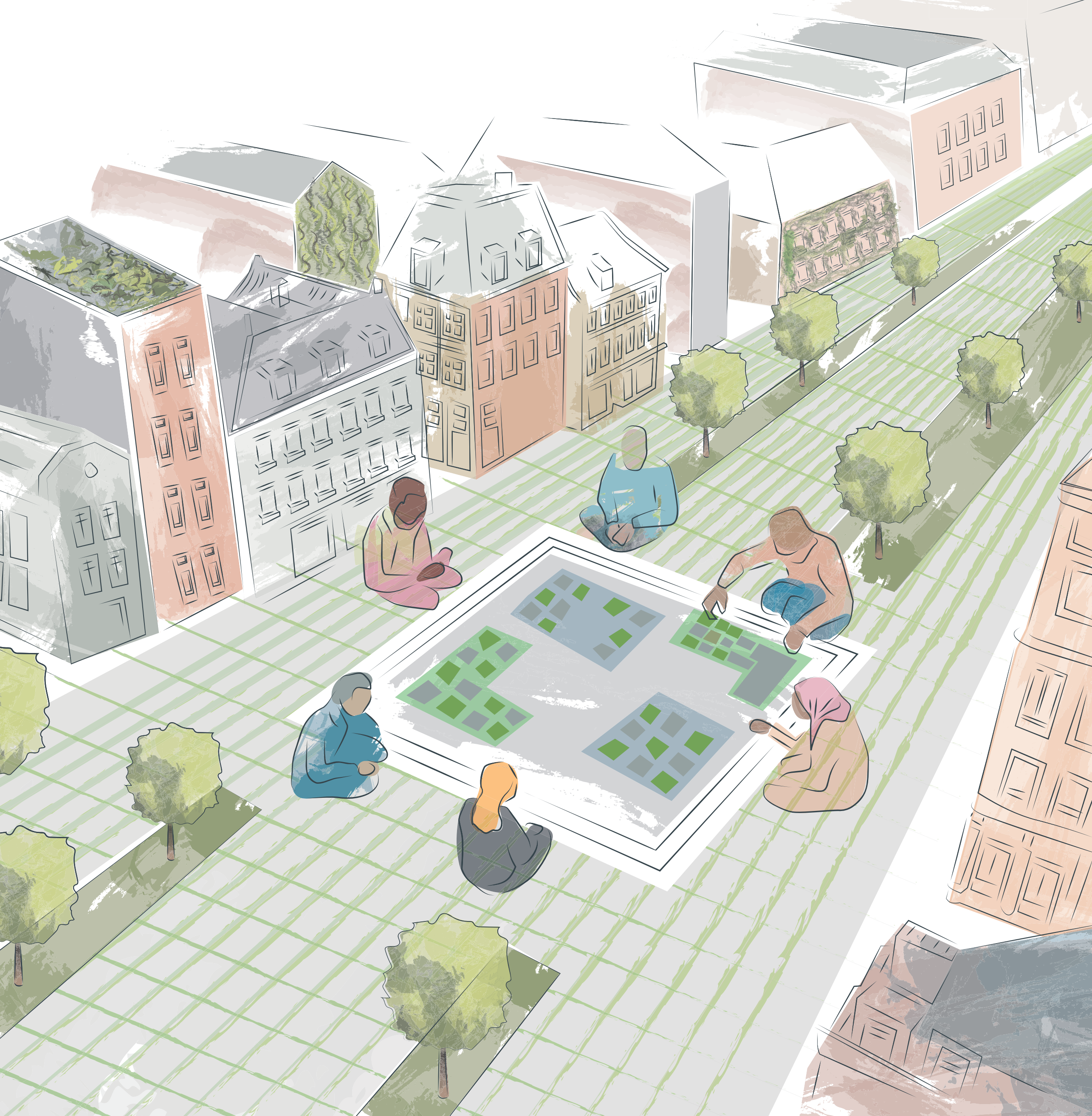

Serious gaming to improve decision-making in urban stormwater management

Aashna Mittal

Serious gaming to improve decision-making in urban stormwater management

Dissertation

for the purpose of obtaining the degree of doctor

at Delft University of Technology

by the authority of the Rector Magnificus, prof.dr.ir. T.H.J.J. van der Hagen,

Chair of the Board for Doctorates

to be defended publicly on

Thursday 4th September at 12:30

by

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To:

Maa, my pseudo “supervisor”
who encouraged me all along my
academic journey

Contents

Summary

Urban areas are highly sealed and already struggle to withstand extreme weather events, the effects of which are expected to get worse with increasing urbanisation and climate change. Despite frequent periods of intense rainfall, there is little room for stormwater to infiltrate into the ground, resulting in high runoff flows (storm water) to the underground sewers. In most cities, this infrastructure was laid hundreds of years ago and is old and deteriorating and does not have sufficient capacity to convey the growing flows to the receiving body or the wastewater treatment plants. This implies that there is a need to re-plan or re-imagine our cities such that existing spaces can be better utilized to store and infiltrate more water while creating co-benefits such as reduced heat stress, increased biodiversity and liveability.

Current decision-making challenges to stormwater management are plentiful. Multiple actors are involved in decision-making across public and private spaces, each with their objectives, preferences for solutions and perceived uncertainties. Firstly, urban residents are not aware of the problem of urban flooding and the options they could implement on their private property. This includes awareness of the urgency and risk of flooding, the sustainable urban drainage systems (SUDS) that could be put on private property, their pros and cons and their impact on flooding and liveability of their neighbourhoods. Secondly, there are lack of platforms for decision-makers to come together and understand interdependencies among them and plan how to upgrade the current infrastructure of cities, i.e., decide the mix of blue, green and grey solutions.

In this thesis, serious gaming is used as the means to address the above decision-making challenges. Serious games are games designed not just to entertain players but to impart 'serious' learning, train a skill, or facilitate cooperation. Serious games are widely used in the water sector to support decision-making but their potential hasn't been fully explored to address decision-making barriers for stormwater management in particular. Hence, in this thesis, the main research question is: *How can serious games be designed and used to improve decision-making for stormwater management?* The thesis has 4 core chapters, Chapters 2 to 5, each addressing a sub-research question.

In Chapter 2, 15 serious games for urban water management (UWM) were mapped to decision-making and game design phases to evaluate their focus and methodologies. The analysis revealed that most games emphasize later decision-

making stages, such as evaluating alternatives while neglecting early foundational decision-making stages like problem structuring and understanding. Many games also lacked engaging design elements, such as backstories and adaptive difficulty, which could enhance immersion, learning, and broader user appeal. Furthermore, evaluation methods often relied on single-group post-tests, limiting the ability to establish causal impacts of the game. Adopting more rigorous designs like randomized controlled trials (RCTs) and using clear decision-quality metrics could significantly improve assessment reliability and effectiveness.

Before designing a game, it was critical to understand how to approach game design and translate the reality and complexity of the urban stormwater management context into a serious game. There are overarching frameworks available in the serious gaming literature that lay out the process and the steps of game design but lack a detailed and structured methodology to do that. In Chapter 3, a methodology for problem and system analysis for serious games based on a Dutch case study of flooding in a small urban neighbourhood is presented. The methods of actor analysis and cognitive mapping were combined to identify relevant actors and capture their perspectives on urban flooding. These were then analysed to understand individual and shared goals, actions, perceived uncertainties and interdependencies among actors, which are mapped and translated into gaming elements such as objectives, player actions, events, and scoring indicators. The methodology proposed in the study helps translate both the technical and decision-making complexity of the urban flooding problem into a conceptual map that can be further used to make choices about the scope and problem to be addressed in a serious game.

In Chapter 4, the prototype and initial evaluation results of a serious game called SUDSbury are presented. The game is targeted at urban residents and is designed to make players aware of the urgency and risk of urban flooding and the measures that can be put on private property to store/infiltrate stormwater. In the game, players adopt the role of a house owner or renter occupying houses/apartments and can choose solutions they want to implement on their private property. Players have to work collectively to ensure that their neighbourhood is not flooded while also competing to make maximal individual contributions to reducing flood risk and improving the liveability of the neighbourhood. The game was designed iteratively, partly based on the methodology proposed in Chapter 3, by conducting a simplified systems analysis using data from desk research and literature. The game was tested with 14 participants and pre-game and post-game surveys were deployed to evaluate the impact of the game. The results obtained showed an overall increase in the participants' average knowledge, comprehension levels, and personal norms towards the adoption of SUDS after playing the game.

Chapter 5 presents the prototype and test results of the serious game Urban dRain. The underlying problem analysis for this game builds on the applied system analysis methodology presented in Chapter 3. The game is designed to bring public (municipality) and private actors (urban residents) together to learn about the interdependencies between their actions and to co-create a future-proof stormwater management plan for a Dutch neighbourhood with significant prevailing architectural heritage. In the first round of the game, public and private actors first look at the problem from their perspective and then come together in the second round to find a collective solution and discuss cost distributions. The performance assessment of solutions was supported by an Excel-based decision support tool to calculate the impact of players' choices on indicators like flood damage, investment and maintenance costs, additional blue-green area added, heritage value and level of nuisance. The game was tested with 70 MSc students with little to no background in Civil Engineering. The post-game results and discussions showed that the game was successful in initiating negotiations among the players and helped them develop a sense of shared responsibility, collective problem solving and awareness about the multi-actor context of urban flooding.

Chapter 6 summarises and presents the key conclusions of the thesis and opportunities for further research. Overall, the thesis demonstrates that serious gaming can be used to support decision-making for stormwater management and presents the prototype and evaluation results of two serious games. Future work should focus on further testing the games with real-world actors and adapting them for similar contexts in the Netherlands and beyond. Furthermore, the methodology for conducting the systems analysis for game design can be further validated by applying it to different case studies and testing the link between the game design process and the design outcome.

Samenvatting

Stedelijke gebieden zijn in hoge maten verhard waardoor zware regenbuien moeilijk opgevangen kunnen worden en steeds vaker tot water overlast leiden. De effecten hiervan zullen naar verwachting erger worden door toenemende verstedelijking en klimaatverandering. Ondanks de veel voorkomende periodes met intense regen, is er weinig ruimte voor regenwater om in de grond te infiltreren, wat resulteert in hoge afvoerstromen (stormwater) naar de ondergrondse rioleringen. In de meeste steden is deze infrastructuur decennia geleden aangelegd en is oud en verslechterd en heeft onvoldoende capaciteit om de groeiende volumes stormwater af te voeren. Dit impliceert dat er behoefte is om opnieuw na te denken over de ruimtelijke planning van onze steden, zodat bestaande ruimtes beter kunnen worden benut om meer water op te slaan en te infiltreren. Dit kan tegelijkertijd co-voordelen creëren , zoals verminderde hittestress, verhoogde biodiversiteit en leefbaarheid.

De huidige uitdagingen op het gebied van besluitvorming voor regenwaterbeheer zijn talrijk. Meerdere actoren zijn betrokken bij de besluitvorming in openbare en particuliere ruimtes, elk met hun eigen doelstellingen, voorkeuren voor oplossingen, en waargenomen onzekerheden Stadsbewoners zijn zich niet altijd bewust van het probleem van stedelijke wateroverlast en de oplossingen die ze op hun privéterrein zouden kunnen implementeren. Dit omvat bewustzijn van de urgentie en het risico van wateroverlast, de duurzame stedelijke drainagesystemen (SUDS) die op privéterrein kunnen worden geplaatst, de voor- en nadelen en impact op overstromingen en leefbaarheid van hun buurten. Ten tweede is er een gebrek aan platforms voor besluitvormers om samen te komen en onderlinge afhankelijkheden te begrijpen en te plannen hoe de huidige infrastructuur van steden kan worden verbeterd: namelijk hoe de mix van blauwe, groene en grijze oplossingen te bepalen.

In dit proefschrift wordt *serious gaming* gebruikt als middel om de bovenstaande uitdagingen op het gebied van besluitvorming aan te gaan. *Serious games* zijn spellen die niet alleen zijn ontworpen om spelers te vermaken, maar ook om 'serieuze' kennis over te brengen, een vaardigheid te trainen of samenwerking te vergemakkelijken. *Serious games* worden veel gebruikt in de watersector om besluitvorming te ondersteunen, maar het potentieel van *serious games* om besluitvormingsbarrières rond regenwater het hoofd te bieden is nog niet volledig onderzocht. Daarom is de hoofdonderzoeksvraag in dit proefschrift: Hoe kunnen *serious games* worden ontworpen en gebruikt om besluitvorming voor regenwaterbeheer te verbeteren?

Dit proefschrift bestaat uit vier hoofdstukken, die elk een deelonderzoeksvraag behandelen.

In hoofdstuk 2 werden 15 bestaande *serious games* voor stedelijk waterbeheer (*urban water management:* UWM) in kaart gebracht. De serious games werden geanalyseerd op de besluitvormings- en game-ontwerpfasen en verdere methodologieën. De analyse liet zien dat de meeste *serious games* de nadruk leggen op de latere besluitvormingsfasen, zoals het evalueren van alternatieven, terwijl eerdere, fundamentele besluitvormingsfasen zoals probleemstructurering en begrip worden verwaarloosd. Veel *serious games* misten ook aantrekkelijke ontwerpelementen, zoals achtergrondverhalen en adaptieve moeilijkheidsgraad. Verbeteringen op deze punten zouden de onderdompeling, het leren, en de bredere aantrekkingskracht naar de gebruiker kunnen verbeteren. Qua evaluatiemethoden wordt er vaak vertrouwd op post-tests met één groep. Dit beperkt het vermogen om causale effecten van de *serious game* vast te stellen. Het aannemen van strengere ontwerpen zoals gerandomiseerde gecontroleerde onderzoeken (RCT's) en het gebruiken van duidelijke statistieken voor de kwaliteit van beslissingen, zou de betrouwbaarheid en effectiviteit van de beoordeling aanzienlijk kunnen verbeteren.

Voordat een *serious game* ontworpen kan worden, is het van cruciaal belang om te begrijpen hoe het ontwerp van de *serious game* moet worden benaderd en hoe de realiteit en complexiteit van de context van UWH in een *serious game* kan worden vertaald. Er zijn overkoepelende kaders beschikbaar in de literatuur over *serious games* die het proces en de stappen van spelontwerp uiteenzetten, maar een gedetailleerde en gestructureerde methodologie ontbreekt om dat te doen. In hoofdstuk 3 wordt een methodologie voor probleem- en systeemanalyse voor *serious games* gepresenteerd, gebaseerd op een Nederlandse casus van wateroverlast in een kleine stedelijke buurt. Actoranalyse en cognitieve mapping methoden werden gecombineerd om relevante actoren te identificeren en hun perspectieven op stedelijk wateoverlast vast te leggen. Deze werden vervolgens geanalyseerd om individuele en gedeelde doelen, acties, waargenomen onzekerheden, en onderlinge afhankelijkheden tussen actoren te begrijpen. Deze aspecten werden dan vertaald in game-elementen zoals doelstellingen, speler acties, gebeurtenissen, en score-indicatoren. De methodologie die in de studie wordt voorgesteld, helpt om zowel de technische als de besluitvormingscomplexiteit van stedelijk wateroverlast te vertalen naar een conceptuele routekaart die verder kan worden gebruikt om keuzes te maken over de reikwijdte en probleemstelling dat in een *serious game* moet worden aangepakt.

In hoofdstuk 4 worden het prototype en de eerste evaluatieresultaten van een het*serious game* SUDSbury gepresenteerd. De game is gericht op stadsbewoners en is ontworpen om spelers bewust te maken van de urgentie en de risicos van stedelijk wateroverlast en de maatregelen die op privéterrein kunnen worden genomen om regenwater op te slaan en te infiltreren. In de game nemen spelers de rol aan van bewonder, in de vorm van huiseigenaar of huurder, en kunnen ze oplossingen kiezen die ze op hun privéterrein willen implementeren. Spelers moeten collectief samenwerken om ervoor te zorgen dat hun buurt niet overstroomt, terwijl ze ook concurreren om maximale individuele bijdragen te leveren aan het verminderen van het overstromingsrisico en het verbeteren van de leefbaarheid van de buurt. De game is iteratief ontworpen, deels gebaseerd op de methodologie die in hoofdstuk 3 is voorgesteld, door middel van een vereenvoudigde systeemanalyse met behulp van gegevens uit deskresearch en literatuur. De game is getest met 14 deelnemers en er zijn enquêtes voor en na de game uitgevoerd om de impact van de game te evalueren. De verkregen resultaten lieten een algehele toename zien in de gemiddelde kennis, het begrip en de persoonlijke normen van de deelnemers ten aanzien van de acceptatie van SUDS na het spelen van de game.

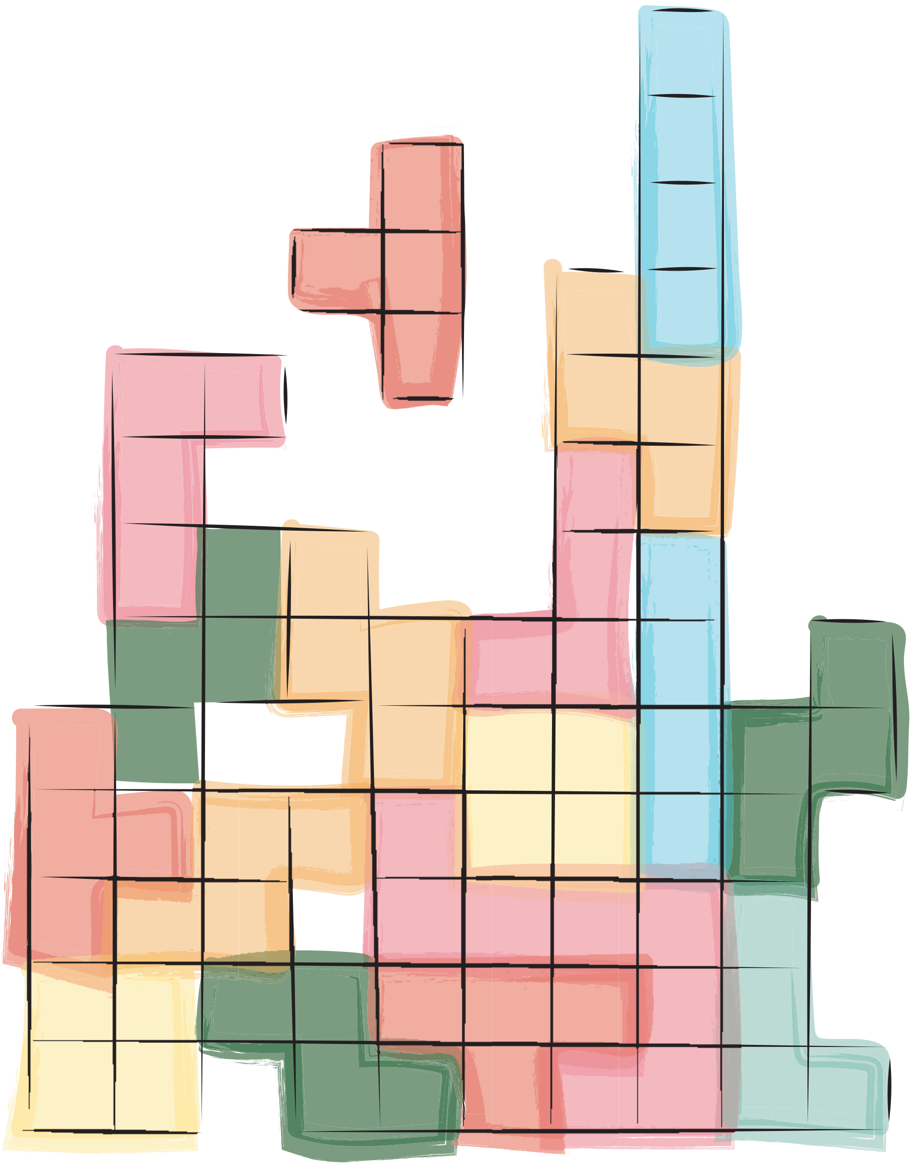
Hoofdstuk 5 presenteert het prototype en de testresultaten van een tweede *serious game*: Urban dRain. De onderliggende probleemanalyse voor deze game bouwt voort op de toegepaste systeemanalysemethodologie die in hoofdstuk 3 is gepresenteerd. De game is ontworpen om publieke (gemeentelijke) en private actoren (stedelijke bewoners) samen te brengen om te leren over de onderlinge afhankelijkheden tussen hun acties en om samen een toekomstbestendig stormwaterbeheerplan te creëren voor een historische belangrijke Nederlandse wijk. In de eerste ronde van de game bekijken publieke en private actoren het probleem eerst vanuit hun perspectief en komen vervolgens in de tweede ronde samen om een collectieve oplossing te vinden en kostenverdelingen te bespreken. De prestatiebeoordeling van oplossingen werd ondersteund door een op Excel gebaseerde hydraulische beslissingsondersteuningstool om de impact van de keuzes van spelers op indicatoren zoals overstromingsschade, investerings- en onderhoudskosten, extra blauwgroen toegevoegd gebied, erfgoedwaarde en mate van overlast te berekenen. De game werd getest met 70 MSc-studenten met weinig tot geen achtergrond in civiele techniek of UWM. De resultaten en discussies na de game lieten zien dat de game succesvol was in het initiëren van onderhandelingen tussen de spelers en hen hielp een gevoel van gedeelde verantwoordelijkheid, collectieve probleemoplossing en bewustzijn te ontwikkelen over de multi-actor context van stedelijk wateroverlast.

Hoofdstuk 6 vat de belangrijkste conclusies van de dissertatie samen en presenteert deze, evenals mogelijkheden voor verder onderzoekDe thesis toont aan dat *serious gaming* kan worden gebruikt om besluitvorming voor UWM te ondersteunen en presenteert het prototype en de evaluatieresultaten van twee *serious games*. Toekomstig werk zou zich moeten richten op het verder testen van de games met echte actoren en het aanpassen ervan voor vergelijkbare contexten in Nederland en daarbuiten. Bovendien kan de methodologie voor het uitvoeren van de systeemanalyse voor gamedesign verder worden gevalideerd door deze toe te passen op verschillende casussen en de link te testen tussen het gamedesignproces en de ontwerpuitkomst.

Nomenclature

AI	Artificial Intelligence
BGI	Blue-Green Infrastructure
CBS	Central Bureau of Statistics
CRC	Climate Resilient City
CSM	Combined Systems Map
CSO	Combined Sewer Overflow
DSS	Decision Support Systems
DST	Decision Support Tool
EPA	Engineering and Policy Analysis
GDPR	General Data Protection Regulation
GDS	Game Design Specification
GW	Groundwater
ICT	Information and Communications Technology
ICUD	International Conference on Urban Drainage
IDT	Invitational Drought Tournament
IPCC	Intergovernmental Panel on Climate Change
LO	Learning Objective
MCDA	Multi-Criteria Decision Analysis
MCQ	Multiple Choice Questions
MRQ	Main Research Question
MUN	Municipality
NAM	Norm Activation Model

NGO	Non-Governmental Organization
OECD	Organisation for Economic Co-operation and Development
OR	Operations Research
PI	Power Interest
RCT	Randomized Controlled Trial
REA	Regional Environmental Agency
RES	Resident
RPG	Role-Playing Game
SRQ	Sub Research Question
SSBC	Stage model of Self-regulated Behavioural Change
SUDS	Sustainable Urban Drainage Systems
SWMM	Storm Water Management Model
TPB	Theory of Planned Behaviour
TU Delft	Technische Universiteit Delft
UI	User Interface
UWM	Urban Water Management
WWTP	Waste Water Treatment Plant



1

Introduction

1.1 | STORMWATER MANAGEMENT IN URBAN AREAS

Cities are becoming urbanized to accommodate more people and economic activity. An unseen consequence of this trend is that urban areas are becoming more prone to pluvial flooding. Pluvial flooding occurs when heavy rainfall overwhelms the capacity of the underground urban drainage systems, leading to the accumulation of runoff water (stormwater) in the streets or parks. Unlike river/fluvial flooding, pluvial flooding results from high-intensity, short-duration rainfall events that exceed the rate of infiltration into the ground and the design capacity of the sewer infrastructure (Falconer et al., 2009). With increasing unplanned urbanization, the surface area of cities is becoming more sealed which means that an increasing amount of stormwater runs off to the sewers, thereby increasing the risk and the frequency of urban flooding. Moreover, climate change effects are leading to an increase in the frequency and intensity of rain showers, particularly across north-western Europe among other regions, further exacerbating the situation (IPCC, 2023; Kyselý et al., 2011).

Pluvial flooding can have multiple impacts (Jha et al., 2012). It can cause significant disruptions in urban areas, damage the built environment, and pose health risks (European Environment Agency, 2024). Infrastructure such as roads, bridges, and public transportation systems can be damaged, leading to disruptions in daily commutes and costly repairs. Residential and commercial buildings may be damaged, leading to high repair costs. Finally, floodwaters are likely to be contaminated and can expose residents to pathogens, thereby posing a health risk (ten Veldhuis et al., 2010). Effective stormwater management planning is crucial to reduce these impacts and enhance the resilience of urban areas (Davis & Naumann, 2017).

The conventional solution to drain stormwater away from urban areas is the use of underground piped systems which may have combined or separate wastewater and stormwater flows. The older parts of many cities typically use a combined system that conveys the flow to a wastewater treatment plant that releases the treated effluent to a natural receiving water body (Butler & Davies, 2004). Such a system is designed to work well during dry weather flows, however, results in sewer discharges and overflows into streets and water bodies during intense rainfalls. Furthermore, in the Netherlands, these systems were historically designed for lower return periods that can no longer withstand the current rate of climate change and urbanization effects, and are deteriorating with time (Brown et al., 2009; Pahl-Wostl, 2006). Retrofitting, upgrading or laying down new and bigger pipes with increased capacity is costly to implement and requires a lot of underground space, disrupts public services, and is unsustainable given long-term climate change uncertainties (Davis & Naumann, 2017; Yazdanfar & Sharma, 2015).

In recent years, there has been a shift towards integrating piped systems with nature-based systems for draining stormwater. Implementation of sustainable urban drainage solutions (SUDS) or blue-green infrastructures (BGIs) is considered an effective strategy to mitigate the impact of urbanization and climate change on the urban water cycle (Dong et al., 2017; Liu et al., 2014). SUDS mimic natural hydrological processes and function as a sponge by absorbing and retaining stormwater at the place where it falls and gradually releasing it, thereby reducing the peak flows (CIRIA, 2015). Some of the SUDS are small-scale and can be implemented at a household level for instance, green roofs, green facades, disconnecting downspouts to a rain garden, and converting paved backyards or front yards into permeable pavements. Others require more space and are suitable for bigger public spaces such as swales, retention ponds or constructed wetlands. Apart from providing the function of urban drainage, SUDS have many co-benefits (Alves et al., 2020; Choi et al., 2021) such as reducing heat stress, improving air quality (Pugh et al., 2012), increasing biodiversity and aesthetics, and contributing to health and well-being by providing spaces for recreation and relaxation (Geary et al., 2023; Scott, 2023).

Although there are different approaches to dealing with stormwater, the first challenge is that often the combination of solutions to adopt is not clear. A one-size-fits-all approach does not work and the details and specificities of an area need to be taken into account at a local/neighbourhood level (Gimenez-Maranges et al., 2020). Secondly, even though multiple technical solutions are available, rarely does a single actor (i.e. stakeholder) have control over the adoption of these solutions. Stormwater management planning is socio-technical and there are many public and private actors involved in the decision-making around the adoption of solutions, each with their own objectives, formal responsibilities, and world views (Ekmekcioğlu, 2024; Nickel et al., 2016; Qiao et al., 2018). Therefore, the specific decision-support needs of the actors need to be taken into account.

1.2 | DECISION-MAKING CHALLENGES IN STORMWATER MANAGEMENT

Multiple public and private actors are involved in the decision-making around stormwater management and these actors have different interests and objectives requiring trade-offs to be made (Dhakal & Chevalier, 2016). Public actors like municipalities, water boards, and utility companies manage solutions in public spaces, while private actors like homeowners or tenants are responsible for private spaces. Researchers, universities, technical companies, and NGOs serve as knowledge brokers or solution providers for both groups. In this thesis, I focus on two key challenges concerning the above actors and their decision-making and dive deeper into the support that needs to be provided to improve the decisions. I first look into the educational needs of private households and then move onto a broader actor context looking into the cooperation challenges between public and private actors.

1.2.1 | Awareness among private households

The role of urban residents is critical in the transition towards sustainable stormwater management (Hegger et al., 2017). More than 60% of built-up area in Dutch cities is residential (CBS, 2023), and therefore, residents have a significant opportunity to implement stormwater management solutions on their property and reduce the peak of stormwater that runs off to the underground sewers. However, a lack of knowledge and awareness about SUDS among urban residents hinders widespread adoption (Krijnen, 2020; O'Donnell et al., 2017; Roy et al., 2008; Winz et al., 2014). Furthermore, the lack of awareness of private responsibility towards stormwater management leads to passivity and inaction among residents and results in governmental actors going beyond their duty of care (Dai et al., 2018).

There are multiple reasons behind the low adoption of SUDS among private households. Among others, residents are not fully aware of the increasing risk of pluvial flooding due to climate change and urbanization and do not feel the urgency to act and change their behaviour (Brockhoff et al., 2019). Unlike surface water, stormwater is "hidden" as it traverses through a network of underground pipes and infiltrates into the ground. There is a general lack of awareness about the urban water cycle, the limited capacity of underground sewers and the possible solutions that can be put on the land to slow down the stormwater (Bassone-Quashie, 2021). Furthermore, information about the range of household SUDS along with their impacts on flood risk, costs, and other co-benefits is lacking. Tools are needed to effectively engage private residents and increase their awareness about the problem of pluvial flooding and dive deeper into the pros and cons of specific solutions that they could implement.

1.2.2 | Cooperation among public and private actors

As the stormwater management infrastructure of urban areas needs to be upgraded and transitioned towards a more sustainable approach, multiple actors need to cooperate and work together (Ekmekcioğlu, 2024; Nickel et al., 2016). The implementation of stormwater management approaches, especially the closer-to-source strategies such as SUDS, typically requires the acceptance and collaboration of both public and private actors (Ekmekcioğlu, 2024). Even though some residents are aware of the urgency of acting towards addressing pluvial flooding and the different solutions that can be put on private land, they are dependent on public actors for subsidies, funding support or knowledge about the suitability of specific solutions at the neighbourhood level (Dai et al., 2018). Similarly, public actors are dependent on residents to implement solutions that can create additional stormwater storage on land and reduce the peak runoff to the sewers, especially in areas where there is a lack of space available to implement SUDS in public areas.

The involvement of relevant actors in the decision-making process is important to ensure that conflicting goals are aired and negotiated and uncertainties are understood (Davies et al., 2023). Often, a planning process starts with the municipality or the public actor coming up with a tentative solution (often with the support of an engineering consulting company) and then seeking feedback from the private residents to gather acceptance (Dai et al., 2018). However, these approaches remain at the lower tiers of citizen participation (Arnstein, 2019) and engagement (Dobre et al., 2021). There is a need for engaging strategies that bring together actors affected by stormwater management plans that help create a shared understanding of the problem – the key actors, their roles and perspectives, objectives and responsibilities, interdependencies among them and possible actions and solutions. This is also critical for actors to assume a collective responsibility for the problem of urban flooding and explore solutions together as part of the initial phases of decision-making.

1.3 | MAPPING DECISION SUPPORT NEEDS TO DECISION ANALYSIS PHASES

To address the above barriers for public and private actors, it is crucial to assist actors with tools and methods to systematically evaluate relevant information and make and explore decisions. Research fields like operations research, decision support systems, and decision analysis offer different ways to support decision-making. In this thesis, I use the lens of decision analysis which is an interdisciplinary approach that focuses on following a structured process to ensure a high-quality decision (Eisenführ et al., 2010; Keeney, 1982). This involves framing the problem correctly, generating diverse alternatives, gathering reliable information, clarifying values and trade-offs, using logical reasoning to choose among alternatives, and committing to the chosen decision (Spetzler et al., 2016). It's important to note that decision analysis is different from decision support. It uses conceptual and quantitative models to structure and support decision-making through various stages, going beyond the quantitative assessment of impacts and (perceived) 'objective' cost-benefits (Hamouda et al., 2009; Makropoulos & Savíc, 2019; Vojinovic & Abbott, 2017) without consideration for subjective valuations and priorities (Hartmann et al., 2021; Scholten et al., 2017).

Decision analysis typically involves six phases that can be carried out in series or parallel (Figure 1-1; see Chapter 2 for details): problem structuring, defining objectives and attributes, developing alternatives, estimating consequences of alternatives, evaluating trade-offs and selecting alternatives, and finally, implementing, monitoring, and reviewing decisions. The process begins by demarcating relevant actors, their roles, responsibilities, resources, and perspectives. An appropriate problem scope is selected in this phase by the analyst in consultation with the actors. Objectives or goals of the actors are then identified, requiring decision-makers to consider fundamental goals beyond cost minimization, which are then converted into measurable attributes. In Phase 3, alternatives are shortlisted such that a broad range of choices is present, such as covering both blue, grey and green solutions for stormwater management.

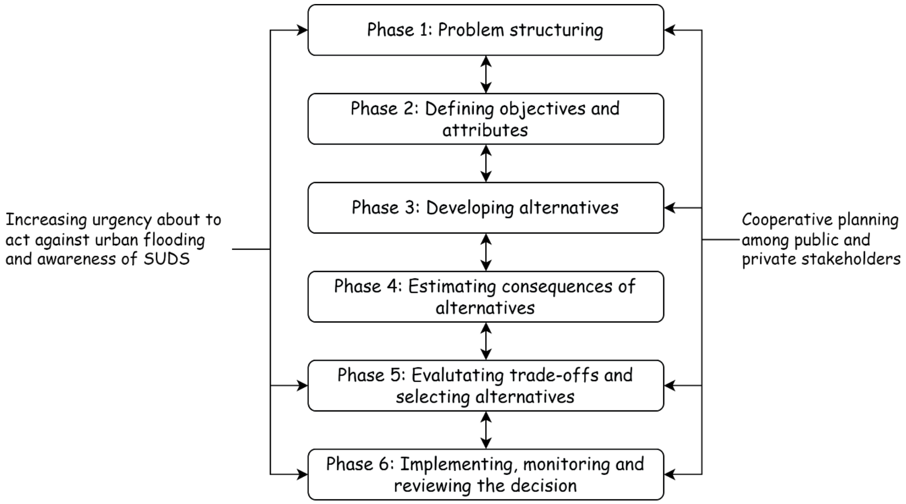


Figure 1-1: Decision analysis phases

Once the alternatives are defined, their performance on the attributes identified in the previous phase can be determined using expert judgement, and mathematical models of varying complexity. In the fifth phase, the preferences of the decision-makers are elicited and alternatives are evaluated, often aiming to facilitate discussions about trade-offs rather than identifying a single best option. In phases 4 and 5, depending on the goal and the support that the decision-support process aims to offer, the performance assessment and evaluation can range from the application of simplified and qualitative models to more complex and detailed mathematical models. Finally, the implementation and real-world impact of the decision are monitored, potentially leading to a new decision cycle. As this may be costly to do in the real world, a decision-support tool can offer multiple decision-making rounds where the decision from one round is implemented and reflected on in preparation for the next round.

Given the two decision-support gaps identified in Section 1.2, I further delve into the specific support that is needed for the gaps by mapping them onto the decision-analysis phases, as shown in Figure 1-1. To address the lack of awareness among private residents about the urgency of urban flooding and the relevant household SUDS that can be implemented to reduce flood risk, support for Phases 1, 5 and 6 is required. Firstly, in Phase 1, urban residents need to be made aware of the general problem context of urban flooding, why it matters, what current urban areas look like and what might happen if no action is taken. Secondly, as in Phases 5 and 6, residents must be able to explore different household SUDS options, select and implement them, and get feedback on their pros and cons and a general sense of their performance on key criteria. These could be the multitude of co-benefits that SUDS provide such as improved air quality, heat stress, increased biodiversity, improved run-off water quality and so on.

Similarly, addressing cooperation among public and private actors requires support for Phases 1, 3, 5 and 6. Firstly, actors need to increase their system knowledge and as part of Phase 1, understand their role and responsibilities as well as those of other actors, and their actions and interdependencies. Secondly, in Phase 3, instead of one actor proposing a solution and seeking feedback, they need to collectively look for possible solutions, i.e., how to combine different SUDS options with grey options like sewer upgrades. Lastly, as in Phases 5 and 6, actors can go through multiple iterations of finding possible solutions and evaluating them, while discussing any conflicts as they arise, in terms of different priorities for criteria or any legal or resource-related barriers or dependencies that need to be resolved before a solution can be implemented.

There are multiple decision-support tools (DST) that have been built to support stormwater management planning, looking into topics such as the assessment of stormwater control measures, their benefits and values, and the effectiveness of the overall management approach (Sun et al., 2024). These tools have a narrow focus on Phase 4 and Phase 5 of decision analysis, aiming to find an optimal solution for a single actor by diving deep into the performance assessment of a limited set of solutions. Although there is a consensus on involving actors and their diverse viewpoints, efforts are mainly directed towards the technical development of DSTs, neglecting multi-actor decision-making aspects. Therefore, there is a need for engaging tools, ones that can simplify the problem context and provide a platform for diverse actors to come together and explore solutions and resulting conflicts. In this thesis, I use serious games as a method/tool to support the decision-making needs identified in this section.

1.4 | SERIOUS GAMES FOR ADDRESSING DECISION SUPPORT NEEDS

Play is essential to human existence. Humans play to overcome a challenge, to connect with other people and create a sense of community, to have fun, and to escape the routine of daily life and suspend themselves into an imaginary world. Playing is a free activity that is outside the realm of ordinary life, engaging and absorbing with uncertain outcomes and without the need to produce something or gain any material profit (Huizinga, 1980; Murphy et al., 2013; Rodriguez, 2006). A game is a means to play, an activity that is further bounded by rules, resources, location, and time. Games provide a sense of autonomy, competence and relatedness which makes them attractive to play (Ryan et al., 2006). While games are primarily meant to have fun, enjoyment or entertainment, often we can derive meaningful learnings from the gaming world for the real world.

The notion of serious games was first introduced by Abt (1970), the idea being that games can be specifically designed not just for entertainment but for a more "serious" purpose such as education, training, behaviour change, and supporting decision-making among many others (Djaouti et al., 2011; Michael & Chen, 2006). In complex systems, where it is difficult and costly to experiment with decisions in the real world, serious games are a good tool to experiment with decision-making in a safe, simulated environment. Players can explore different options, try them out and learn from the feedback that the game provides. Additionally, serious games can be used to educate on a specific topic and be used to develop negotiation, collaboration, and problem-solving skills (Romero et al., 2015). Serious games are also a medium for reflection as they nudge players to reflect on their choices and behaviour in the suspended reality of the gaming world and draw learnings about the consequences of their current behaviour in the real world.

Serious games have been around for more than two decades and have been widely used to improve decision-making across different domains such as asset management (Rissanen 2020), healthcare (Damaševičius et al., 2023), education (Cheng et al., 2015; Young et al., 2012), sustainability transition (Stanitsas et al., 2019), climate adaptation (Flood et al., 2018), business management (Grund & Meier, 2016) and many more. More specifically, serious games are becoming a popular tool for decision support for urban water management problems (Aubert et al., 2018; Savic et al., 2016) which is evident from the large number of serious games (more than 40) on urban water management issues that have been developed already. These games cover a wider range of topics such as drinking water access, quality and distribution, pluvial flooding, fluvial flooding, drought management, river floodplain management and many more, targeting actors that range from the general public to policymakers and designed for varied purposes such as decision-support, training, knowledge sharing or data collection (see Chapter 2).

To better understand the gaps in the current serious game applications, I started with a systematic and detailed review of 15 serious games designed for urban water management decisions more broadly (more details in Chapter 2). From the review, it was clear that there is a lack of serious games that support early phases of decision-making where the problem context and scope are defined and decision-makers can gain a general understanding of the decision context and its elements – actors, their objectives, resources, actions and perceived uncertainties and so on. More specifically, there are no serious games designed to tackle stormwater management issues in particular, i.e., to educate citizens about urban flooding and corresponding solutions and bring multiple actors together to develop collective solutions at a neighbourhood scale.

To design a serious game to address these issues, I started by looking into the serious game design literature to understand the current game design frameworks that guide a game designer through the design process. Most game design frameworks are generic, with 5 broad phases starting with Phase 1: *Design Specifications* where the game's purpose, use, and target audience are defined in consultation with the relevant actors. Then on, moving to Phase 2: *Systems Analysis* where important elements of the real-world system are identified such as actors and their relationships, processes, technical concepts, uncertainties, etc. This phase generally leads to a conceptual visualization of the overall problem and the real-world system being analysed. Then in Phase 3, *Detailed Game Design*, the outcomes of Phase 2 are translated into gaming elements and mechanics starting with a rough design and making choices such as the game format, rules, players, scenarios, scoring mechanisms and so on. Then the game is constructed, built, and validated in Phase 4: *Game construction, testing and validation* with a test audience and finally implemented and evaluated with the target audience in Phase 5: *Game implementation and evaluation*.

Designing a serious game that meets the two decision-making gaps for stormwater management identified in the previous sections required an understanding of the real-world socio-technical system. Although the game design frameworks are useful and provide a general guideline about the design process, they lack a structured process and detail on how to capture, simplify, reduce and translate the real-world system into the gaming world. This forces the game designer to rely on intuition and experiences and makes it difficult to trace back the choices made in the problem scope and selection of the part of the system that will be taken further into the serious game. The downside of this lack of clarity and structure is that the choices may be hard to reproduce and may also lead to a bias to the worldviews and cognition of the game designer. Furthermore, once a conceptual overview or a map of the real-world system is realized, it is unclear how to translate them into specific game elements. Indeed, this is a creative and iterative process, but without some further guidance on how this translation can be done, the process and choices behind most game design applications remain elusive and untransparent. Therefore, I use a systems analysis methodology borrowed from methods used in the field of policy and decision analysis to execute the initial phases of serious game design and to bring structure into Phases 1, 2 and 3 of serious game design.

1.5 | SCIENTIFIC KNOWLEDGE GAPS: DESIGN AND USE OF SERIOUS GAMES FOR MULTI-ACTOR STORMWATER MANAGEMENT DECISION-MAKING NEEDS

Sustainable stormwater management is critical to ensure that cities remain flood-proof and prepared to deal with the uncertainties of climate change and rapid urbanization. Finding a solution to this problem may seem straightforward but that's not the case. Many technical studies exist that focus on finding an optimal solution for a single decision-maker but the reality of the problem is far from this situation. Rarely does a single actor have control over the problem of urban flooding. I argue that a multi-actor perspective is needed to address this issue, considering the perspectives of different actors and their decision-making needs. Before diving into specific solutions, more support is needed at the early levels of decision-making where actors can understand the problem first, the role of different actors, their actions, resources and interdependencies. To do this, I want to move away from conventional DSTs and propose the use of serious games as a means of decision support. I see the following research opportunities that can together address the design and implementation of serious games that incorporate the multi-actor perspective and can support the decision-making needs of actors in stormwater management:

1. A better understanding of the current serious game applications being used to support decision-making for urban water management problems. There are many examples of serious game applications, however, it is not clear how these serious games currently support decision-making processes – which decision analysis phases they address, and how (well) are these games designed and evaluated. Getting insights into the gaps in current serious game applications will provide insights into which phases of decision-making should be supported by future serious game applications.

2. Current game design frameworks lack a structured process and analytical methods to incorporate the multi-actor context of a real-world problem into games. The serious game design literature does not shed light on how to model the real world and come to a conceptual map of the socio-technical system being analysed. Although system analysis is considered a critical step in game design, current serious game applications hardly present the details of the underlying systems analysis, which implies that the choices and decisions behind scoping the problem that is presented in the game are neither transparent nor reproducible. Looking into relevant problem structuring methods that can be used to execute the initial phases of serious game design would help game designers better translate the real-world system into the game world.
3. SUDS can help combat pluvial flooding in urban areas by providing additional storage and infiltration capacity resulting in an overall reduction of peak run-off to the sewers. However, the adoption of these solutions remains low as private residents lack the urgency to act and the awareness of the household SUDS options. There is a need for a tool that can bridge this gap by introducing the urban flooding context to urban residents in a simplified and engaging way. Compared to the traditional ways of engagement such as pamphlets or information campaigns, serious games can be a means to increase problem awareness and allow residents to explore different SUDS and their impacts. Currently, no serious game exists to bridge this gap. I see this as an opportunity to use serious games as a tool for educating the general public about urban flooding.
4. Looking only into the decision support needs of private households is not enough as often a stormwater management strategy at a neighbourhood level requires multiple actors to cooperate and implement solutions both in the public and private space. Current tools focus either on a single decision-maker and do not bring multiple actors together to look into their potentially conflicting objectives and actions. These tools have a technical focus on finding the optimal solution which may not be adopted if the multi-actor complexity is not taken into account. Hence, I see an opportunity here to develop a serious game that can bring multiple actors together and provide them a platform to understand their roles, actions, resources, and interdependencies and explore the solution space individually and collectively.

1.6 | RESEARCH QUESTIONS AND APPROACH

Based on the knowledge gaps identified in the previous section, the main question for this research is as follows:

How can serious games be designed and used to improve decision-making for stormwater management?

The overall aim of this research is to contribute to improved decision-making and problem-understanding for actors involved in stormwater management by means of serious games. To achieve this aim and answer the main research question, this thesis presents four studies (see Table 1-1) that look into different aspects of this question. The approach adopted in this thesis is a combination of conceptual and empirical work. The first study is a systematic review of the state-of-the-art with respect to serious game design for supporting urban water management decisions. The second study presents a methodology for serious game design that can help translate the complexity of the real world into the gaming world. The third and fourth studies are empirical in nature, presenting the design of 2 serious games – SUDSbury and Urban dRain that aim to improve the decision-making of public and private actors involved in stormwater management. The research is interdisciplinary in nature combining decision analysis, policy analysis methods, serious game design and applying it to the problem context of stormwater management.

The sub-research question for each study/chapter is presented below along with the approach and methodology used to answer the question:

I. What are the knowledge gaps in the decision support and design of current serious game applications?

   Specific objective: The objective of this question is to review the existing serious game applications designed to improve or support decision-making for urban water management decisions and highlight the current gaps and directions for future research.

   Approach (see Chapter 2): The approach taken to answer this question is to conduct a narrative review of the serious games and map them to common decision-making phases to better understand which phases are supported by existing games and what are the corresponding gaps. Similarly, the games were also assessed in terms of their game design and evaluation approaches

Table 1-1: Overview of thesis chapters, knowledge gaps and methods used

Sub research question	Chapter	Knowledge gap	Type of contribution	Research method
1	2	Gaps in current serious game applications designed to support UWM decisions in terms of their decision-support, design and evaluation methodologies.	Review	Narrative review
2	3	A structured methodology to analyse the real-world system for serious game design	Methodology for serious game design	Interviews, systems mapping, cognitive mapping, case study
3	4	An engaging tool to educate urban residents about the context of pluvial flooding and develop the urgency to act and adopt SUDS	Design prototype, empirical testing	Serious game design and testing
4	5	A platform to bring public and private actors involved in stormwater management together and facilitate collective solution development	Design prototype, empirical testing	Serious game design and testing, case study

to get a sense of what success factors are currently deployed in the games and what methods are deployed to evaluate the impact of the game (if at all).

II. How can the multi-actor complexity of stormwater management be incorporated into the design of serious games?

Specific objective: The objective of this research question is to come up with a structured process and methodology to capture, simplify, and translate the real-world system into the gaming world.

Approach (see Chapter 3): A combination of two policy analysis methods – actor analysis and cognitive mapping are used to conduct the initial phases of serious game design that serve as the preparation and foundation for mapping key elements of the real world and selecting a suitable problem scope to be represented in the serious game. The methodology is demonstrated for a case study in the Netherlands struggling with urban flooding problems. The case study was selected due to ongoing pilot projects on sewer upgrades, interest to use a serious game, and access to stakeholders in the case study area. Stakeholders are first mapped using actors analysis and then semi-structured interviews are conducted to capture actor perceptions. The interview data is visualized into actor-level and system-level cognitive maps which are further analysed to demonstrate the process of problem analysis and translation of the problem into game design elements. The general methodology and the outcomes of this study are used to design serious games in Chapters 4 and 5.

III. How can a serious game educate urban residents about household SUDS?

Specific objective: The objective of this question is to develop and evaluate a serious game aimed at educating the public on household SuDS and increasing support for their implementation among general citizens.

Approach (see Chapter 4): The study presents the design and implementation of a serious game called SUDSbury targeted at urban residents with minimal background in urban water management. The game is designed to represent the perspective of renters and homeowners in the game and introduce them to the problem of urban flooding and different SUDS options that can be implemented on private land. I draw from the literature on education and behaviour change to conceptualize the measurement of the game's educational effectiveness. The game is evaluated by conducting play-test sessions with 14 participants and deploying pre-post surveys.

IV. How can a serious game foster collaboration among actors involved in stormwater management in Dutch neighbourhoods?

Specific objective: The objective of this question is to develop and evaluate a serious game aimed at bringing public and private actors in stormwater management together and improving their understanding of the problem, solution space and dependencies among them.

Approach (see Chapter 5): The study presents the design and testing of a serious game called Urban dRain targeted at a diverse set of actors in stormwater management. The game is designed for a Dutch case study and represents the perspectives of private households and municipalities. These groups are challenged to first look at the problem of urban flooding from their perspective and then come together as a joint group and look for a collective solution. A simplified multi-criteria analysis is presented to the players to provide feedback on their choices. The game is evaluated by conducting play-test sessions and deploying post-game surveys.

1.7 | THESIS STRUCTURE AND READING GUIDE

This thesis is organized into six chapters and you can navigate it as shown in Figure 1-2. The Introduction chapter outlines the problem context of stormwater management, the specific decision-making needs of different public and private actors and the research objectives around the design and use of serious games to address those needs. Chapter 2 provides a rich landscape of serious games designed for urban water management decisions more broadly. Here, 15 serious games are mapped to common decision-making and game design phases to evaluate current contributions and gaps. In the review, I found that there was a lack of systematic systems analysis conducted for designing the current applications. Hence, in Chapter 3, I address the gap by presenting a structured approach for conducting systems analysis where the real-world stormwater management problem is analysed and translated into a systems map that can be further used for game design.

The empirical contributions are detailed in Chapters 4 and 5: Chapter 4 focuses on the educational game "SUDSbury," designed to raise awareness about sustainable urban drainage systems among private households, while Chapter 5 introduces "The Urban dRain Game," which facilitates actor cooperation in co-developing stormwater management solutions at the neighbourhood scale. The thesis concludes in Chapter 6, where you get an overview and summary of the research objectives, outcomes, key contributions, and directions for future research.

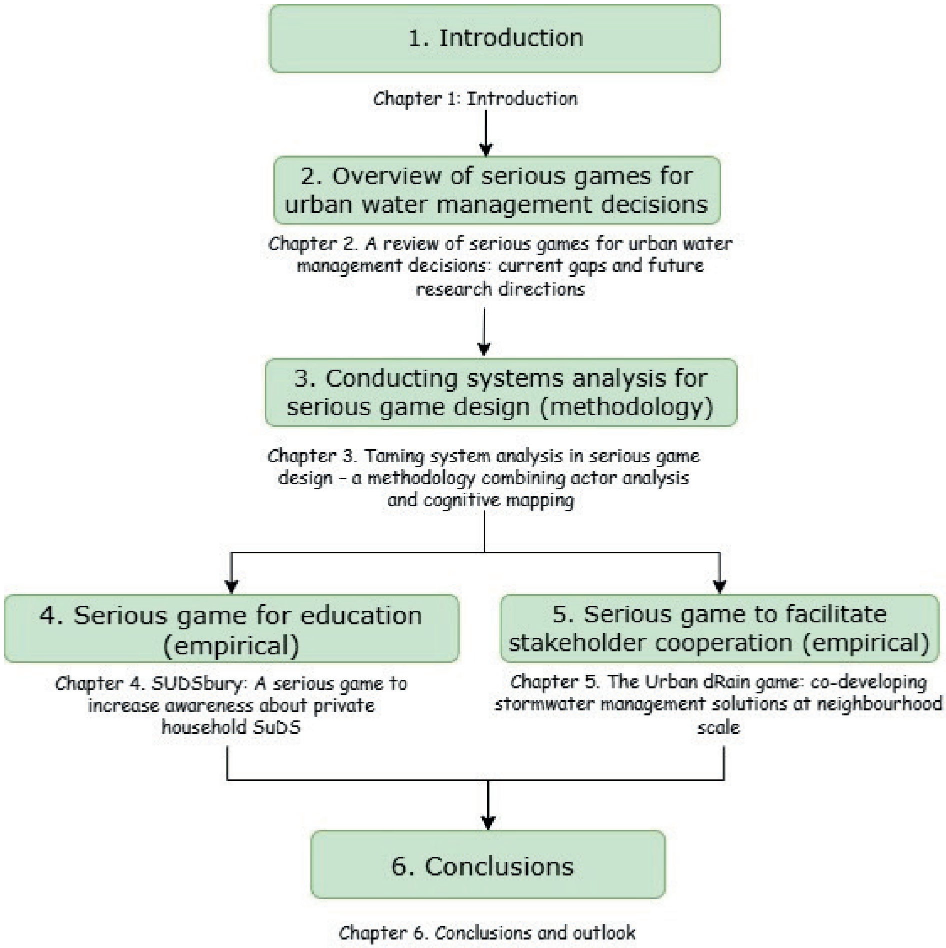
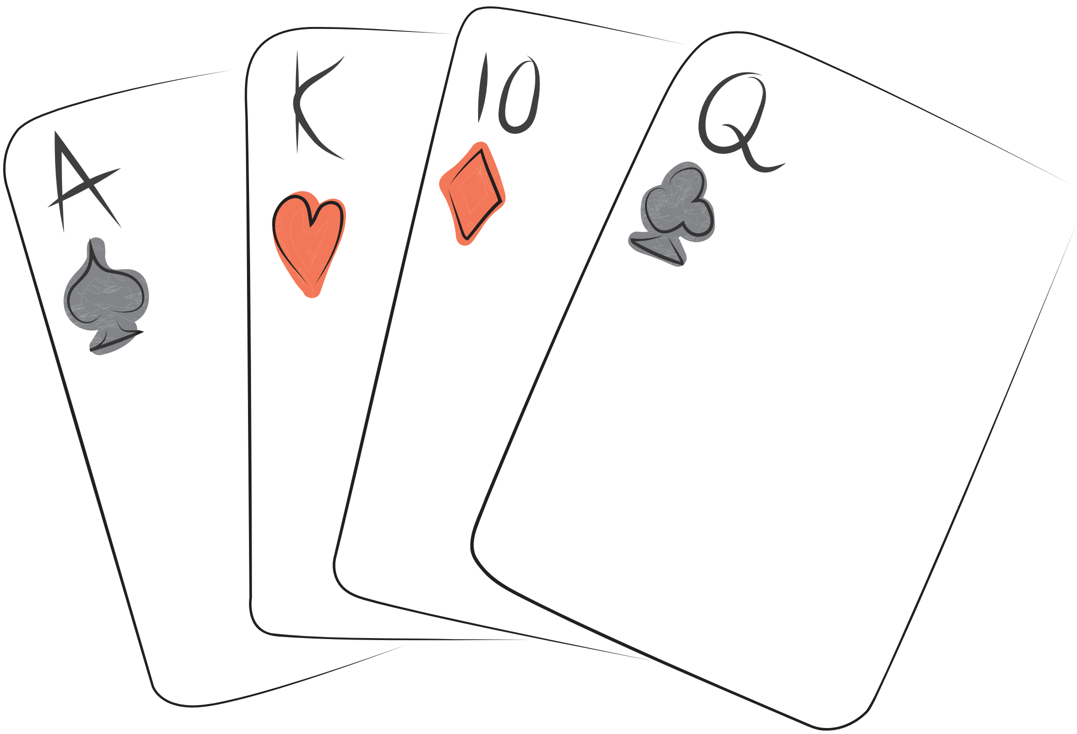


Figure 1-2: Thesis outline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A review of serious games for urban water management decisions: current gaps and future directions

This chapter is based on: Mittal, A., Scholten, L., & Kapelan, Z. (2022). A review of serious games for urban water management decisions: current gaps and future research directions. Water Research, 215, 118217.
https://doi.org/10.1016/j.watres.2022.118217

ABSTRACT

Decision-making for urban water management (UWM) is a complex problem characterized by multiple alternatives, conflicting objectives, and multiple uncertainties about key drivers like climate change, population growth, and increasing urbanization. Serious games are becoming a popular means to support decision-makers who are responsible for the planning and management of urban water systems. This is evident in the increasing number of articles about serious games in recent years. However, the effectiveness of these games in improving decision-making and the quality of their design and evaluation approaches remains unclear. To understand this better, in this chapter, we identified 41 serious games covering the urban water cycle. Of these games, 15 were shortlisted for a detailed review. By using common rational decision-making and game design phases from the literature, we evaluated and mapped how the shortlisted games contribute to these phases. Our research shows that current serious game applications have multiple limitations: lack of focus on executing the initial phases of decision-making, limited use of storytelling and adaptive game elements, use of low-quality evaluation design and explicit indicators to measure game outcomes, and lastly, lack of attention to cognitive processes of players playing the game. Addressing these limitations is critical for advancing purposeful game design supporting UWM.

2.1 | INTRODUCTION

The health and growth of a city are strongly interlinked with water. A city depends on urban water systems to collect, treat, manage, and distribute drinking water, wastewater, groundwater, surface water, and stormwater (adapted from Larsen and Gujer, 1997). Today, urban water systems face immense pressure. On the one hand, they need to serve multiple functions such as protecting public health, reducing the risk of flooding, supporting urban agriculture, and providing water of sufficient quantity and quality for domestic use and recreational purposes (Larsen and Gujer, 1997). On the other hand, urban water systems must deal with the challenges of climate change, population growth and rapid urbanization. To ensure that urban water systems are future-proof, a transition to sustainable urban water management (UWM) is imperative (Brown et al., 2009). This entails strategic planning and adopting alternatives that deliver sustainable outcomes in the long term.

To achieve sustainable UWM, decision-makers such as municipality officials or water utility managers need to make decisions concerning how to adapt the urban water systems to reduce the risk of pluvial flooding (Alves et al., 2020). To do so, they need to select and assess a large number of relevant grey, blue, and blue-green measures while balancing conflicting social, economic, and environmental objectives. Decision-making is further complicated by uncertainty about future developments that influence the technical, biophysical environment and the social context of the urban water system. Consequently, decision quality is often limited, including the omission of promising alternatives, reliance on unreliable information or logically incorrect reasoning, lacking clarity of values and trade-offs at stake nor ensuring commitment to action by other crucial actors, among other elements that ensure quality decisions (Spetzler et al., 2016). Hence, for such complex decisions, decision-makers often rely on facilitated decision-making processes to ensure decision quality.

Serious games are gaining popularity as a means to support decision- making processes in the water sector. These are games that "do not have entertainment, enjoyment or fun as their primary purpose" (Michael and Chen, 2006); instead, they aim to educate, train, motivate and induce behavior change (Ritterfeld et al., 2009). Serious games are an engaging way for decision-makers to experiment and learn things within a game setting that can be later transferred to real-world problems. The popularity of serious gaming is evident in the manifold games that have been developed in the water sector to enable learning about complex problems and support decision-making (Aubert et al., 2018; Madani et al., 2017; Savic et al., 2016).

Although serious games are ubiquitous, it is not clear from the current literature how these games improve decision-making, i.e., which phases of structured decision-making processes do current gaming applications support, in what way, and which aspects need further attention. Furthermore, a common limitation of existing serious games is that their impact is not studied and the quality of their design is often not evaluated (Mayer, 2012; Mitgutsch and Alvarado, 2012). Recent reviews (Aubert et al., 2018; Savic et al., 2016) reiterate the need to systematically study the design and evaluation of serious games in the water sector. In this chapter, we build on this issue by examining the design and evaluation approaches for UWM serious games (i.e. games covering issues related to the urban water cycle) and highlight aspects that need improvement.

To address the above challenges, the following research questions are answered in this chapter:

1. *How do UWM serious games map to common decision-making phases?*
2. *How do UWM serious games map to common game design and evaluation approaches?*

We answer these questions by identifying relevant UWM games and critically analyzing their contributions and limitations to the decision analysis, game design and evaluation processes. By doing this, we aim to improve the design and usability of serious games for structured decision-making and highlight future research directions.

The outline for the chapter is as follows. In Section 2.2 , we highlight common phases followed in a decision-making process that follows procedural rationality as well as serious game design and evaluation phases. In Section 2.3, the methodology to select and analyze relevant UWM games is presented. In Section 2.4, the mappings of selected games to decision-making and game design and evaluation phases are presented. In Section 2.5, gaps for future research are highlighted and the conclusions are presented in Section 2.6.

2.2 | SERIOUS GAMES FOR DECISION-MAKING

2.2.1 | Decision-making challenges in sustainable UWM

Cities are increasingly subjected to UWM challenges such as growing population, climate change effects, and rapid urbanization. Urban water systems in most developed countries across Europe and North America were built a long time ago

(Hering et al., 2013) and are not equipped to withstand these pressures. Failure to rehabilitate these systems may lead to serious issues in the coming decades (Ashley and Cashman, 2007), e. g., water supply shortage or supply with substandard water quality, pluvial flooding issues due to insufficient system capacity to accommodate extreme rainfall affected by climate change, increase in the risk of fluvial flooding due to dike failures, increase in pollution of surface water bodies and other recipients, deterioration of ecosystems, to name but a few.

To ensure that urban water systems are climate-proof and future-proof, we need a transition towards a water-sensitive city, one where the city acts as a water supply catchment, provides ecosystem services, and comprises water-sensitive communities (Brown et al., 2009; Ferguson et al., 2013). This entails breaking away from the conventional UWM approaches and undertaking a major technical overhaul through wider uptake of innovative alternatives such as decentralized ('non-grid') water supply and wastewater alternatives (Hoffmann et al., 2020; Kiparsky et al., 2013; Larsen et al., 2016; Marlow et al., 2013), using stormwater and wastewater as a resource, using water for reduced heat stress, among other alternatives. However, this is a complex planning process with many challenges.

Long-term planning involves multiple actors each with their own objectives, values, and perceptions about the problem. Typical actors include water utilities, municipalities, different government agencies and water boards, consultants and researchers, civil society, and non-governmental organizations (NGO) among many more. These actors have different objectives for the planning of urban infrastructure (Lienert et al., 2015; Skrydstrup et al., 2020), e.g. water utilities may prioritize low costs, safety and security, government agencies might focus on the health and well-being of citizens, whilst advocacy organizations may be driven by nature conservation. Given the multitude of objectives and agendas that are brought to the forefront by different actors, it becomes critical to search for alternatives that perform well across multiple objectives.

Furthermore, decision-makers can choose from a plethora of available alternatives that need to be evaluated. These could be large-scale alternatives such as transitioning from centralized water collection and treatment to decentralized systems or increasing the capacity of the existing infrastructure, i.e. pipes, pumping stations, and wastewater treatment plants (Butler and Davies, 2004). Other available alternatives include implementing blue-green infrastructures to store stormwater and reduce runoff to sewerage pipes. These alternatives range from deploying green roofs, constructing pervious pavements, collecting roof runoff in rain barrels, implementing flood parks, disconnecting downpipes from sewers, or constructing ditches to temporarily store water and allow it to sink slowly into the ground (Amsterdam Rainproof, 2021; CIRIA, 2015).

However, even if a shortlist of relevant alternatives is made and there are reliable ways to measure the performance of these alternatives, the impact of these alternatives may vary across criteria and indicators thereby forcing decision-makers to make trade-offs. For example, increasing pipe capacity may cost more but has higher flood risk reduction potential whereas green-blue infrastructures cost less but have limited water retention capacity (Alves et al., 2020). Similarly, installing green roofs may on the one hand reduce the amount of stormwater runoff but on the other hand, it can expose the runoff to nutrients such as phosphorus and nitrogen used in fertilizers thereby reducing the quality of stormwater (Pataki et al., 2011).

Furthermore, the above decisions need to be taken under pervasive uncertainties. For instance, climate change is expected to cause more frequent and severe storms in Central Europe (e.g Kyselý et al., 2011) resulting in more stormwater that must be drained by the urban drainage infrastructure. Similarly, population growth, increase in urbanization, together with complex interactions between the social and environmental systems, further add to planning uncertainty. Not to mention the ever-present legislative, policy, and technological development uncertainties. All these uncertainties make it difficult to estimate the future consequences of the alternatives under consideration and hence increase the complexity of related decision-making.

2.2.2 | Decision-making phases

As the complexity of planning urban water systems increases, it becomes important to assist decision-makers with appropriate tools and methods to systematically and objectively assess information relevant to the decision problem and make a decision. This has been the focus of multiple research fields such as operations research, decision support systems, and decision analysis, which vary in their approach to supporting decision-making. In this chapter, we use the decision analysis lens to assess and analyse UWM serious games.

Decision analysis is commonly defined as “a formalization of common sense for decision problems which are too complex for informal use of common sense” (Keeney, 1982). It is an interdisciplinary field that aims to improve decision-making by guiding decision-makers through the right procedure of making a decision. Instead of aiming for the outcome of a ‘rational’ decision, this approach strives for procedural rationality (Eisenführ et al., 2010). The rationale is that by following the right procedure, the decision-makers will be able to make a good quality decision which is characterized by choosing the appropriate frame, creating a set of rich alternatives, obtaining relevant and reliable information, clarifying values and trade-offs of decision-makers, using sound reasoning to select the alternatives, and ensuring commitment to implementing the decision taken (Spetzler et al., 2016). It is important to note that decision analysis is not synonymous with decision support nor are these two the same. Decision analysis employs conceptual and quantitative models to structure and support the decision-making process across different phases of decision-making. It goes far beyond the mathematical modeling of alternatives and their outcomes that are at the heart of most of the model-based decision support literature in the water domain (Hamouda et al., 2009; Makropoulos and Savic, 2019; Mannina et al., 2019; Vojinovic and Abbott, 2017).

At the core of decision analysis, six generic phases are usually carried out in series or parallel, if not interlacing (Belton and Stewart, 2002; Eisenführ et al., 2010; Greco et al., 2016; Gregory et al., 2012; Keeney and Raiffa, 1993; Lienert et al., 2015; Pollack, 2009). While their arrangement in time matters for the acceptability and success of the decision process within a specific decision context (see e.g. Henao and Franco, 2016), most frameworks assume a simplistic step-wise procedure to characterize the process and its phases, as shown in Figure 2-1: (1) structuring the problem (2) defining objectives and attributes, (3) developing alternatives (4) estimating consequences of alternatives (5) evaluating trade-offs and selecting alternatives and lastly (6) implementing, monitoring and reviewing the decision.

The starting point of decision-making is a problem that can range from messy and unstructured to well-defined. Therefore, Phase 1 of decision-making focuses on structuring the decision problem, i.e., demarcating relevant actors, their key issues, values, uncertainties, and constraints, and then selecting the appropriate frame of the problem. To achieve decision quality in this phase, actors must agree on a shared frame of the problem by discussing what is the decision problem being solved, how do different actors perceive the problem and what aspects of the problem should be left in and out of consideration (Spetzler et al., 2016). In Phase 2, the underlying objectives of the decision-maker are defined and they are further operationalized into attributes against which the performance of the alternatives is measured. Special attention is required in this phase to support UWM decision-makers to think of their fundamental objectives and go beyond the salient objective of minimizing costs.

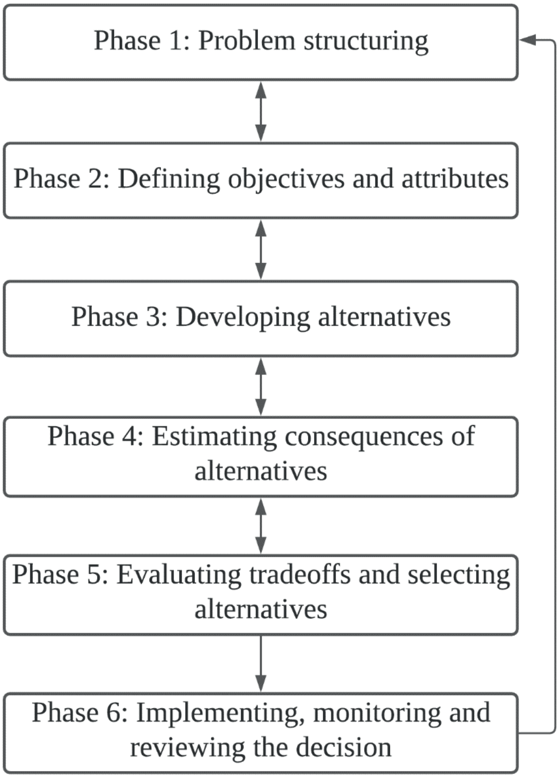


Figure 2-1: Decision-making phases. These phases may not proceed linearly and decision-makers may move back to previous phases, e.g., if in Phase 3 sufficient alternatives cannot be found then decision makers may move back to Phase 1 to broaden the scope of the problem

In Phase 3, promising alternatives are shortlisted. The surfacing of objectives and search for alternatives occur often through iterations. A goal-focused process can indicate directions for developing relevant alternatives from using the identified objectives whereas an alternative-focused process can lead to identifying the objectives that the explored alternatives have a bearing on (Belton and Stewart, 2010). To achieve good decision quality, a set of alternatives that are creative, varied, feasible and representative of a broad range of choices should be prepared through creative thinking techniques such as brainstorming (Spetzler et al., 2016). A common challenge in this phase is to ensure that UWM decision-makers think beyond customary alternatives, e.g., adopting blue-green measures for stormwater management instead of increasing capacity of drainage pipes or recycling/reusing water instead of increasing supply.

Once the alternatives are defined, the consequences of these on attributes can be determined in Phase 4 using expert judgment, available performance data or using mathematical models of different complexity (Scholten et al., 2015). Here, all relevant and reliable information must be considered in anticipating the outcome of an alternative (Spetzler et al., 2016). Once the consequences of alternatives are determined, Phase 5 focuses on eliciting the subjective preferences of the decision-maker(s) towards the alternatives with respect to their consequences. Different mathematical aggregation models can be used to evaluate, sort or rank, the alternatives, depending on the decision problem at hand (Greco et al., 2016; Langhans et al., 2014). Following multi-attribute value and utility theory, a linear additive model is often used to score alternatives. Whilst the applications by researchers for normative purposes typically aim to identify the highest-scoring alternative(s) to propose to a decision-maker, the idea of multi-criteria decision analysis (MCDA) models is to "provide a model for discussion" (Belton and Stewart, 2002) through which learning about trade-offs, construction of preferences, and identification of suitable alternatives is facilitated. Once the decision is implemented in Phase 6, the real-world impact of the decision may be monitored and reviewed, which could lead to initiating another decision-making cycle.

To support one or more decision-making phases mentioned above, serious games are being used to address UWM decision problems, which is evident from the manifold games that have been published (Aubert et al., 2018; Savic et al., 2016; World Water Day, 2018). However, their contribution to decision-making processes has not yet been evaluated. Given their popularity, it is important to understand how current serious game applications map to specific decision-making phases as defined above, thereby revealing the research gaps that still need to be addressed.

2.2.3 | Serious games

A game can be defined as a voluntary activity that immerses a player into an imaginary world that may or may not have a relation to real life. A game is bounded by rules, location, and time and can create a community of players that may last even after the game is over (Huizinga, 1980). Games are attractive to play as they provide a sense of autonomy, competence and relatedness to players (Ryan et al., 2006). Although games are generally thought of as a means of entertainment, more recently they are also being used for `serious' purposes.

The notion of serious games was first introduced by Abt (1970) establishing that games can be used for purposes such as education, decision-making and policymaking. A key advantage of serious games is that they provide an engaging and immersive platform for players to experiment with their decisions, which can be costly to do in the real world. They not only challenge the players to do better but also provide them with a chance to reflect on their behavior within the game and understand its consequences for the real world. What sets serious games apart from other games is that instead of having entertainment as a primary goal (Michael and Chen, 2006) they strive for a more ‘serious’ purpose. Based on the classification by Uskov and Sekar (2014), the purpose of serious games can be divided into the following categories:

1. *Decision-making*: improve decision-making, e.g., accelerating decision-making processes;
2. *Simulation*: face-to-face (in-person) or digital (computerized) simulation of reality;
3. *Sharing of knowledge*: educative or informative games;
4. *Persuasion*: attitude or behavior change;
5. *Data collection/exchange/exploration*: data collection or exchange, research, discovery, innovation, and adventure;
6. *Motivation*: through rewards, badges, and scores;
7. *Training*: practicing or teaching skills such as communication skills, management skills, problem-solving skills, technical skills, or teamwork and collaboration skills.

Serious game design phases

Five phases are generally carried out for the design of serious games, as proposed by Duke and Geurts (2004) and further adapted by Peters and Westelaken (2014). These phases, shown in Figure 2-2, are: (1) Design specifications, (2) Systems analysis, (3) Detailed game design, (4) Game construction, testing, and validation, and finally (5) Game implementation and evaluation.

The game design process starts with Phase 1 where the design specifications of the game are clarified, i.e., the purpose of the game, what the final product should look like and under what conditions will it be used. This phase is carried out in consultation with the client or the intended players of the game. Once the design specifications are captured, the real-world system where the problem lies is analysed in Phase 2. In this phase, important elements to be highlighted in the game are captured e.g. processes, theoretical concepts, actors, information, technical artifacts, and the relations between these elements such as responsibilities, exchange of resources, or information.

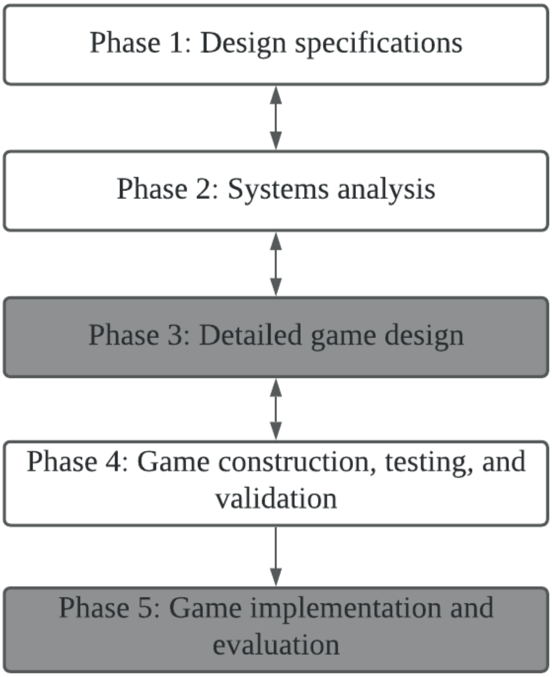


Figure 2-2: Common serious game design phases. Phase 3 and Phase 5 are considered in detail in this chapter as they are used to evaluate the detailed game design and evaluation approach of UWM games

Once the real-world system is captured, the focus of Phase 3 is on translating the real-world elements into game mechanics and game elements. In this phase, the game concept and all game elements are worked out in detail on paper before the actual game is constructed. This involves selecting which elements from the system analysis should be included in the game, how should these elements be represented in the game (e.g. through scenarios, roles, events, analogies, rules, policies, accounting system, scoring, visuals, indicators, story), and what format best suits the game (e.g. board game, card game, computer-based game or an online game).

Although there is no clear consensus on what elements a 'good' serious game must include, Ravyse et al. (2017) identify 5 success factors that impact the learning experience of players: (1) Backstory and production, (2) Realism, (3) Interaction, (4) Feedback and debriefing, and (5) Artificial Intelligence (AI) and adaptivity. A good backstory or game narrative not only engages, immerses, and motivates players but can also significantly enhance the learning experience (Naul and Liu, 2020). Similarly, high-fidelity/realistic games lead to increased game appreciation among the players (Ravyse et al., 2017). By providing a platform for players to interact with each other, serious games can enable players to learn together while creating a feeling of relatedness that can enhance the motivational pull of the game (Ryan et al., 2006). In-game feedback through rewards and punishments provide immediate effects caused by a player's action and post-game feedback helps consolidate the player's learnings (Crookall, 2010; Plass et al., 2015). Lastly, making a game adaptive through the use of AI accommodates players with different skills, learning abilities and learning needs and may even increase the replay potential of games as new scenarios/challenges are encountered across multiple game sessions (Lopes and Bidarra, 2011).

Using inputs from Phase 3, the game is constructed in Phase 4 and converted into a tangible product. This phase is not a one-shot production process but involves ample testing, debugging, validation, and improvement of the game. Lastly, in Phase 5, the meta cycle in which the game is embedded, called the macro cycle (Klabbers, 2009), is designed, starting from briefing session, gameplay, followed by debriefing and evaluation of outcomes. The evaluation of serious games involves both the achievement of the learning goal(s) and other aspects such as participants' engagement, acceptance, game design, performance, user experience, enjoyment, cognition and behavior, and satisfaction with the game (Baalsrud Hauge et al., 2013; Calderón & Ruiz, 2015). In this phase, participants' learning and experience is evaluated through various methods such as questionnaires, interviews, participant observation, and focus group discussions. These methods can be deployed either by a facilitator (if their presence is required) or can be integrated in the game, e.g. by rating the game or filling an online questionnaire after playing the (digital) game.

Furthermore, experimental design approaches are often applied to explain variability of result and to establish a causal relationship between the game contents and the outcomes. The 'gold standard' for such experiments are Randomized Controlled Trials (RCT) as common in statistics, medical and health research and other research fields that draw heavily on experimental design. In RCTs, a sufficiently large number of participants are randomly allocated to different treatments (with intervention) and control group(s) (without intervention) (List et al., 2011). This approach has been adopted for serious gaming in the health sector, where RCTs are commonly used, as they can control over confounding effects and the difference in outcomes between the control and the treatment group can be attributed to the game intervention (Gentry et al., 2019; Primack et al., 2012). Other non-experimental or quasi-experimental approaches to ascertain the effect of games are also commonly applied – e.g. single-group post-evaluation or pre-and-post testing. These suffer, however, from low internal validity than RCTs in terms of establishing causal effects (see further Marsden & Torgerson, 2012; Shadish et al., 2001).

Although serious games are increasingly being used as part of the decision-making process, there is a risk of placing high hopes in games without acknowledging that poor game development and evaluation can undermine these ambitions. Hence, in this chapter, we assess the detailed design (Phase 3) and evaluation (Phase 5) approaches of selected serious game applications with respect to best practices described above.

2.3 | METHODOLOGY

2.3.1 | Study selection

To answer the research questions posed in this chapter, we opt for a narrative review of games that are designed to support decision-making for UWM issues. This method is most suited when researchers aim to gain an initial impression of the research area without the aim of being exhaustive in their search (Bryman, 2012). Following this method, we analyze a small but representative set of serious games. The procedure followed for selection, appraisal, and analysis of articles for this review is described below:

Search strategy and keywords

A search strategy refers to the process followed for finding relevant papers. We initiated our search by scanning key review papers on serious games in the water sector (Aubert et al., 2018; Savic et al., 2016) and browsing the gaming websites (Geneva Water Hub, n.d.; World Water Day, 2018). A broader search was further conducted in Google Scholar, Scopus and IEEE Explore databases. To conduct this search, the keywords were divided into the following categories to cover the topics of serious games and urban water management:

- Category A: Serious gam*, Simulation gam* (an asterisk was used to include different forms of the same word, e.g., gam* to include both game and gaming in the search)

- Category B: urban water, urban water manag*, urban water planning, urban water infrastructure

These keywords were further used in search strings to cover different combinations of keywords in the above categories. Therefore, the search strings covered the combinations "(A1 OR A2 OR A3 ...) AND/OR (B1 OR B2 OR B3 ...)". The bibliography of articles found through this search was further scanned for relevant references. A total of 41 serious games were identified this way. These were further shortlisted for a detailed review based on the selection criteria shown in the next section.

Selection criteria

To select games relevant for this chapter, we applied the following criteria on the set of 41 games:

1. Games covered in recent academic papers: Only serious games in papers published from the year 2010 onwards were included in the review. Although we found relevant commercial games as well (e.g., Dowino, 2019; IBM, 2010; Michigan State University (MSU), 2018; Ram Jam, 2021; University of California Berkley (UCB), 2014), these were left out due to limited documentation about their game mechanics and game design processes.
2. Game purpose and format: In addition to games aimed at improving decision-making, we also consider games designed for other purposes (described in Section 2.2.3), since these games may also contribute to one or more phases of decision-making. For example, data collection games may help monitor and understand decision-maker's current preferences or their decision-making behavior. Moreover, we consider both digital and non-digital serious games that could occur in different formats - card games, board games, simulation games, or a role-playing game implemented with or without the use of a computer.
3. Gaming applications: We only include 'game' applications, not stand-alone simulations (e.g., Makropoulos et al., 2008; Willuweit and O'Sullivan, 2013) or ICT tools (e.g., Pahl-Wostl et al., 2003). Furthermore, we excluded publications that only present frameworks to use a game (ElSawah et al., 2015) or ideas to improve an existing game (D'Artista and Hellweger, 2007) without developing the game application.
4. Urban/peri-urban water management problems: We only include games that are focused on urban or peri-urban water management issues (referred to in this chapter as UWM games). Games focused on more broad water

management problems were excluded (e.g., Douven et al., 2014; Dray et al., 2006; Stefanska et al., 2011; Sušnik et al., 2018).

5. Decision-makers and types of decisions: We include games that are targeted at UWM professionals or have been tested/played with them. These professionals could be government officials, water managers, private enterprises, research institutes, journalists, urban planners, environmental organizations, policymakers, and NGOs. Games targeted at the education or engagement of the general public or students (Appel et al., 2019; Arbesser-Rastburg and Fuchs-Hanusch, 2019; Aubert and Lienert, 2019; Cheng et al., 2019; Hirsch, 2010; Predescu et al., 2021; Rebolledo-Mendez et al., 2009; Rusca et al., 2012) are not included in the review. Furthermore, we cover games that involve both individual and group decision-making and decisions made at the strategic, operational or tactical level.

The initial set of 41 papers was first assessed based on their title, abstract, and conclusion to check if they matched the selection criteria. Whenever this information was insufficient, the articles were read more thoroughly. A total of 15 games were selected this way for further analysis. Supplementary material A in Mittal, Scholten and Kapelan (2024a) provides additional information about the excluded games, including the reasons for exclusion. An overview of the 15 shortlisted games is provided in Table 2-1 along with the following additional information:

1. *Topic*: the focus area of the game within UWM problems.
2. *Game purpose*: the intended aim of the game as declared by the game developers.
3. *Game purpose category*: categories as defined in Section 2.2.3: decision-making, simulation, knowledge sharing, persuasion, data collection/ exchange/exploration, motivation, or training.

Table 2-1: Overview of shortlisted UWM games

Game No.	Game Name	Authors	Topic	Game purpose	Game purpose category
1	Call for water	Crochemore et al. (2021)	Water supply management	The aim of the game is twofold: (1) train participants in the concepts of forecast sharpness and reliability, and (2) collect participants' decisions to investigate the levels of forecast sharpness and reliability needed to make informed decisions	Training, data collection
2	Invitational Drought Tournament (IDT)	Hill et al. (2014); Wang & Davies (2015)	Drought management, drought preparedness, and response planning	Challenge players to consider the holistic impacts of drought and develop consensus around solutions. The IDT tournament combines a workshop with gaming features to (1) improve understanding of drought (2) enable participants to share their experiences of dealing with drought (3) improve collaborative decision-making and consensus-building approaches	Simulation, decision-making, knowledge sharing (informative)
3	LA water game	McBurnett et al. (2018)	Management of aging water distribution infrastructure	Teach systems thinking skills required to support infrastructure resilience. The problem represented in the game is maintaining the quality of the Los Angeles water distribution infrastructure over 75 years while adhering to financial, quality, and public approval constraints.	Decision-making, knowledge sharing (informative)
4	Maintenance in Motion	van Riel et al. (2016); van Riel et al. (2017)	Infrastructure management	This game intends to investigate the influence of information quality and cooperation between people on operational decision-making for urban infrastructure management	Data collection
5	Management Game Asset Management	Van den Boomen et al. (2012)	Asset Management	The game helps employees of a water utility company understand different asset management roles and responsibilities. The game highlights the specific asset management development issues of the organization and encourages employees to find solutions that work	Decision-making, knowledge sharing (educative), training
6	Millbrook Serious Game	Khoury et al. (2018)	Pluvial flood prevention	Improving participants' understanding of the Millbrook flooding problem by enabling them to explore different flood mitigation options and use inductive reasoning to challenge their initial assumptions about the problem and reject/confirm the related hypothesis	Decision-making, knowledge sharing (informative)

Game No.	Game Name	Authors	Topic	Game purpose	Game purpose category
7	No game name	Gomes et al. (2018)	Sustainable and equitable access to drinking water	Enable participants to explore drinking water problems, and experiment with problem-solving strategies (both in current and future scenarios) before engaging in real-world negotiations.	Decision-making, simulation, knowledge sharing (informative)
8	Perspective-based simulation game	Valkering et al. (2013)	River floodplain management; climate adaptation	To deal with water-society interaction, discontinuity, and surprise with respect to climate adaptation. In the game, players take on the role of a water manager and respond to developments in the water-society system under changing scenarios.	Simulation, decision-making
9	SeGWADE	Savić et al. (2016)	Capacity upgrade of a drinking water distribution system	Learn how to effectively manage a water distribution system (WDS) by understanding conflicting objectives (cost vs pressure) and developing a low-cost solution	Simulation, knowledge sharing (educative)
10	Ter' Aguas	Ducrot & Barban (2008)	Water and land management	Facilitate conflict resolution stemming from the impact of urbanization on the irrigation infrastructure, build stakeholder capacity in relation to negotiation processes, and help them assess alternative local and shared alternatives.	Decision-making, training (negotiation skills)
11	The Climate Game	Zhou et al. (2013)	Urban planning and associated water management issues	Enable stakeholders to work together to develop integrated plans to deal with climate change, provide better insights in water management and spatial planning, create policy support, and increase consciousness of future developments and spatial planning in a city	Simulation, decision-making, knowledge sharing (informative)
12	Visimple	Söbke & Londong (2017)	Explore pathways of evolution of water infrastructures	Enable citizens to design, explore, trace and visualize the consequences of urban water infrastructure transitions at the system level and use those results in a civic decision-making process and facilitate non-expert knowledge acquisition	Simulation, decision-making

Game No.	Game Name	Authors	Topic	Game purpose	Game purpose category
13	Wastewater RPG	Prat et al. (2009)	Improve wastewater infrastructure management	To appreciate outcomes of formal decision-making on performance of waste-water management infrastructure by simulating decision-making among multiple actors discharging wastewater into a common river	Simulation, decision-making, data collection
14	Water Safety Plans	Ferrero et al. (2018)	Drinking water quality	Raise awareness about the added value of a water safety plan, enable players to practice stakeholder engagement while making strategic decisions, and demonstrate the importance of collaboration and stakeholder integration in decision making	Decision-making, simulation, knowledge sharing (informative), training
15	WATERSTORY	Bassi et al. (2015)	Sustainable management of municipal water supply	Create a common understanding of current and future water management challenges, promote the participation of relevant stakeholders to assess and evaluate policies, and support integrate decision-making	Simulation, knowledge sharing (informative)

2.3.2 | Analysis

In this chapter, each game presented in Table 2-1 was analysed based on information available in the academic publication or by playing the game (where possible). For instance, the first author played the SeGWADE game online. Information on decision phases and game design phases was extracted for each game and mapped onto the decision-making and game design phases presented in Sections 2.2.2 and 2.2.3.

Decision-making phases

To map the serious games to decision-making phases, the following three levels of mapping are defined:

- *Well addressed*: the decision-making phase is executed in the game.
- *Partially addressed*: the decision-making is partially executed in the game and its implementation can be improved.
- *Not addressed/ no information*: the decision-making phase is not executed in the game or no information is provided in the paper.

When mapping the games to decision-making phases it was found that some games are not implemented as a stand-alone game but embedded into a larger workshop/process where players could be involved in the early phases of decision-making. In these cases we also considered the contribution of activities conducted in addition to the game session towards decision-making and game design phases. For example, if a game only presented pre-decided alternatives to players, then it was considered to not contribute to Phase 3 (*Developing alternatives*) of decision-making. Opposite of this, if the players were involved in developing alternatives, either while developing the game or in the game session, then that game was considered to contribute to Phase 3.

Game design phases

To map the selected games to Phase 3 (Detailed game design), gaming elements were categorized for each game using the following success factors identified by Ravyse et al. (2017):

1. Backstory and production: storyline or narrative of the game.
2. Realism: resemblance of the game to real-life.
3. Interaction: interaction among the players and between the game interface and the player.
4. Feedback and debriefing: in-game cause-and-effect feedback and post-game debriefing.

5. AI and adaptivity: dynamic adjustment of game response/challenge based on the player's skills, learning ability and learning needs.

Similarly, Phase 5 (*Implementation and evaluation*) of each game was assessed by extracting information on:

1. Evaluation methods and research approach used: post-test design, pre-test/post-test design, RCT or a similar approach.
2. Characteristics assessed during evaluation (adapted from Calderón and Ruiz, 2015):
3. Learning goals: achievement of game objective (with or without explicit indicators).
4. Game design: mechanics, realism, rules, level of detail, aesthetics.
5. Game complexity: clarity and ease of understanding.
6. Player experience: ease of use, playability aspects, satisfaction.
7. Player engagement: interaction with user interface/players, enjoyment and fun.
8. Cognition and behavior: impact on player's emotions, mood, attention-level.

The results of the above analysis are presented in Section 2.4.

2.4 | RESULTS

2.4.1 | Mapping serious games to decision-making phases

Table 2-2 presents the mapping of serious games reviewed in this chapter to decision-making phases (see supplementary material B in Mittal, Scholten and Kapelan, 2024a for more details). A common observation across all games is that none addressed all phases of the decision-making process. In order of the decision-making phases, Phase 1 (*Problem structuring*) was covered in 4 games, Phase 2 (*Defining objectives and attributes*) was covered in 3 games, and Phase 3 (*Developing alternatives*) was covered in 4 games. In games that covered Phase 1 (#5, 7, 10, 15), players were involved in demarcating the decision problem tackled in the game. In Ter' Aguas (#10) and WATERSTORY (#15), companion/group modeling approach was used to identify the key water issues, actors and their negotiation strategies and recreate the real-world problem in the game.

In Game 7, interviews and focus group discussions were conducted with relevant actors to identify their main concern – access to safe drinking water supply. The serious game was then designed to provide more insight into this problem. In the

Table 2-2: Decision-making phases covered by UWM games (X = well addressed, (X) = partially addressed, blank = not addressed/no information)

No.	Game Name	Phase 1: *Problem Structuring*	Phase 2: *Defining objectives and attributes*	Phase 3: *Developing alternatives*	Phase 4: *Estimating consequences of alternatives*	Phase 5: *Evaluating tradeoffs and selecting alternatives*	Phase 6: *Implementing, monitoring, and reviewing the decision*
1	Call for water				X	X	X
2	Invitational Drought Tournament (IDT)			X	X	X	
3	LA water game				X	X	X
4	Maintenance in Motion				X	X	X
5	Management Game Asset Management	X				X	
6	Millbrook Serious Game				X	X	X
7	No game name	X	(X)	(X)	X	X	X
8	Perspective-based simulation game				X	X	X
9	SeGWADE				X	X	X
10	Ter' Aguas	X	(X)	(X)	X	X	X
11	The Climate Game				X	X	X
12	Visimple				X	X	(X)
13	Wastewater RPG				X	X	X
14	Water Safety Plans				X	X	
15	WATERSTORY	X	(X)	(X)	X	X	X
	Total	4	3	4	14	15	11

Management Game Asset Management (#5), Phase 1 was executed in the game itself as the players discussed problems within different departments in the organization and the differences in their perception about asset management. In contrast, games in which Phase 1 was not covered adopted a decision problem either as pre-determined by previous work (e.g., #9), took a known real-world problem (#2, 3, 6), or tested a hypothesis (#1, 4).

Few games in which Phase 1 was covered also implicitly covered Phases 2 and 3 (#7, 10, 15). Although specific methods to find fundamental objectives of the intended players or generate new alternatives were not deployed in these game, it is implicit that the companion modeling workshops and actor consultations were used to develop a broader understanding of actors' objectives and seek suggestions for relevant alternatives. This was not the case for Management Game Asset Management (#5) because the alternatives and objectives were pre-decided and provided to the participants in the game. In IDT (#2), Phase 3 was well covered as the game allowed players to come up with their own creative drought management alternatives, termed as "innovations", thus encouraging them to think beyond conventional alternatives such as water use restrictions, increasing irrigation efficiencies, or developing wetlands.

In comparison to the first three phases of decision-making, the later phases received much greater attention in the games reviewed. Phase 4 (*Estimating consequences of alternatives*) was covered in 14 out of 15 games. In most games, computer models and tools were deployed to determine the consequences of alternatives. These ranged from system dynamics or integrated assessment models in IDT (#2), LA water game (#3), perspective-based simulation game (#8), WATERSTORY (#15) to capture causal relations to a simple Excel spreadsheet as used in Wastewater RPG (#13). In other games, a simpler approach was adopted as they used fictitious case studies and performance numbers as in Water Safety Plan (#14) or provided relevant pieces of information to the players, e.g., current and forecasted reservoir volumes as in Call for Water (#1) based on which players could take decisions.

Phase 5 (Evaluating trade-offs and selecting alternatives) was covered in all games. This was expected since most games reviewed in this chapter aim to support decision processes, where the player decides the gameplay. In this phase, players evaluated trade-offs spanning across economic, social, or environmental objectives. For instance, in the Climate game (#11), players could choose from a list of decisions such as improving housing conditions, developing more green areas or water storage facilities and evaluate the tradeoffs in performance of these alternatives on values of quality of life, costs, added water storage capacity, water safety, and climate-proof advantage.

Lastly, Phase 6 (Implementing, monitoring, and reviewing the decision) was covered in 11 out of 15 games. In these games, the decision was not implemented in the real world but in the gaming environment, often simulated using an underlying model. In some games player's in-game decisions were even monitored and recorded for further analysis. For instance, in the Call for Water (#1) and Maintenance in Motion (#4) games, players' decisions were monitored to understand the relation between the quality of information provided in the game and the decision-making strategies adopted by the player.

In addition to the individual frequencies of each decision-making phase, it is evident that Phases 4, 5, and 6 are most frequently covered in the analyzed games (covered in 11 out of 15 games). These games were typically played in multiple rounds and used an action-reaction feedback loop. In such a loop, players first chose from a set of alternatives. Then their decision was either fed into a model or led to certain rule-based consequences. Once confronted with the impact of their decision, players learn from the game reaction and re-formulate their strategy for the next round.

2.4.2 | Assessing game design and evaluation

Table 2-3 provides an overview of game design elements used in the selected games as mapped to five success criteria – backstory and production; realism; interaction; feedback; AI and adaptivity that are associated with enhanced learning from games (Ravyse et al., 2017).

In 5 out of 15 games (#6, 8, 10, 12, 14) reviewed in this chapter, backstory was incorporated in the game design by setting the scene through a short introduction or play. For instance, the perspective-based simulation game (#8) started by introducing the players to the present situation of management of river Waas through a story. In the game Visimple (#12), a virtual engineer gave a short introductory speech hinting at optimization "hot spots" to the player and guided the player throughout the game by providing context-specific feedback. In the other 10 games, story elements such as a narrative, virtual agents, or a non-player character were not explicitly incorporated. Instead, the players were only introduced to the game objectives at the start of the game.

Regarding realism, all serious games incorporated elements to make the game resemble reality. Various approaches were used for this: assigning roles to players based on real-world actors, using realistic scenarios, high-fidelity visuals such as geographical maps, visualizing the terrain and geography of the real-world area on the game board or through 3D technology, and rounds to simulate different climatic conditions.

In all games players could interact with the game or with each other in some form. The most common approach used to stimulate player-to-player interactions was

Table 2-3: UWM games mapped to success factors for game design phase 3: detailed game design.

Game no.	Game name	Backstory and production	Realism	Interaction	Feedback	AI and adaptivity
1	Call for water	-	Rounds to simulate dry and wet years; role-playing	Players must click the game interface to select decision	Number of game tokens; good decisions rewarded	-
2	Invitational Drought Tournament (IDT)	-	Watershed dynamics based on real-world data; climate measurement visuals; drought scenarios	Cooperative play	Team scoring at game end	-
3	LA water game	-	Real newspaper articles, videos, and events	Cooperative play	Performance indicators; debriefing interviews	-
4	Maintenance in Motion	-	Use of street maps; infrastructure deteriorates between rounds	Cooperative play; interactive map	Track other player's actions, performance indicators	-
5	Management Game Asset Management	-	Role-playing; own company taken as reference	Gathering support for proposed alternative	Score updates; plenary discussion after each round	-
6	Millbrook Serious Game	Introduction to Millbrook flood problem and its historical context	Informative visuals showing the flood area, its terrain and flood surfaces	3D virtual table; move, rotate and zoom features; temporal slider	Flood damage information and performance indicators	-
7	No game name	-	Role-playing; game board represents the geography of the real-world area; element of uncertainty	Cooperative play	Game money; players rate satisfaction after each round; debriefing	-
8	Perspective-based simulation game	Story about starting situation	Virtual stretch of Maas river; role-playing; white papers; switching coalitions; contextual developments presented as headlines	Negotiation between coalitions	Water system impacts, brief discussion on results after each round; debriefing	-

Game no.	Game name	Backstory and production	Realism	Interaction	Feedback	AI and adaptivity
9	SeGWADE	-	Visual pipe network laid on a geographical map; players can lay parallel pipes	Interactive UI with buttons, pipe diameter selection wheel, and pop-up information	Leaderboard; performance indicators	-
10	Ter' Aguas	A short introductory play to establish game context	Role-playing; maps; information sheets	Cooperative play	Performance indicators; debriefing	-
11	The Climate Game		Role-playing; 2D and 3D spatial environment resembles real-world area; realistic flood forecast data	Cooperative play; interaction with computer simulation	Performance indicators; intermediate debriefing; post-game debriefing	-
12	Visimple	- Introductory "speech" by a virtual engineer; non-player agent	Visualizations based on real-world GIS data; descriptive texts; events	Interactive UI; menu to select actions	Context-sensitive feedback provided by virtual engineer; performance indicators	-
13	Wastewater RPG	- -	Role-playing; realistic scenarios	Interaction with a virtual workspace	Performance indicators	-
14	Water Safety Plans	Introduction to case study	Role-playing; realistic scenarios	Cooperative play	Post-game discussion	-
15	WATERSTORY	-	Realistic scenarios	Interaction with simulation tool (customize assumptions, select variables to display, run simulation)	Performance indicators; debriefing	-

2

through cooperative playing where players negotiated and discussed to agree on a common strategy (e.g., #2, 3, 4, 7, 10, 11 14). Other than that, digital games such as Call for Water (#1), Millbrook Serious Game (#6), SeGWADE (#9), Visimple (#12), and WATERSTORY (#15) allowed players to interact with the game interface. Players explored the game environment by clicking, moving or zooming in on objects in the game and selecting their actions.

Feedback mechanisms were incorporated in all games in some form. This was done either by visualizing performance indicators, game scores, or organizing debriefing to let players reflect on the game strategy and the results. In several games (e.g., #3, 5, 7, 8, 10, 11, 14, 15) debriefing was also implemented at the end of each round or in the middle of the game to provide more frequent feedback and reflection to the players.

A common observation across all games reviewed in this chapter is that AI and adaptivity elements were not incorporated in any game, i.e., individual characteristics of a player such as skill level, learning ability or learning needs were not taken into account. This is also recognized as one of the limitations in Call for water (#1) game where the authors mention that the game difficulty should be adapted to match the player's level of knowledge (Crochemore et al., 2021).

Concerning Phase 5 (Implementation and evaluation), Table 2-4 summarizes the evaluation methods and experimental approach and the characteristics assessed. In 7 out of 15 games (#1, 2, 3, 4, 8, 14, 15), a post-game evaluation approach was used by conducting a debriefing session, discussion, or asking players to fill a questionnaire. In 4 games (#6, 7, 10, 11) a single group pre-game and post-game design was used by conducting interviews or discussions. In 3 games (#5, 9, 13), participants were observed by a facilitator or their in-game decisions were logged to evaluate the game impact whereas no information on evaluation was provided by the game Visimple (#12).

To know whether a game achieved its purpose, it is not only important to evaluate the performance of the game on learning outcomes but also aspects such as game design, game complexity, player experience, player engagement and cognition and behavior. In the 15 games reviewed in this chapter, the frequency of characteristics evaluated were as follows: learning goals (evaluated in 13 games), player experience (4 games), game design (2 games), game complexity (2 games), player engagement (1 game). Cognition and behavior-related aspects were not evaluated by any of the games. This indicates that characteristics other than learning goals are often under-evaluated. Moreover, among games in which learning goal was evaluated, explicit criteria was used in only 6 games (#1, 3, 4, 6, 7, 9) to measure the game impact.

Table 2-4: UWM games mapped to game design phase 5: game implementation and evaluation

No.	Game Name	Methods and experimental approach	Characteristics assessed
1	Call for water	Post-game survey; analysis of in-game decisions and survey results	Learning goals (explicit criteria)
2	Invitational Drought Tournament (IDT)	Post-game questionnaire	Player experience
3	LA water game	Participant observations; post-game debriefing interviews followed by data analysis	Learning goals (explicit criteria)
4	Maintenance in Motion	Recording of player's actions; post-game survey on player experience followed by data analysis	Learning goals (explicit indicators); game design; game complexity; player experience
5	Management Game Asset Management	Observation of in-game discussions	Learning goals (no explicit criteria)
6	Millbrook Serious Game	Pre-game and post-game questionnaire	Learning goals (explicit criteria)
7	No game name	Facilitated group discussions; qualitative comparison of pre-workshop discussion and post-workshop debriefing	Learning goals (explicit criteria); game design; game complexity; player experience
8	Perspective-based simulation game	Post-game plenary discussion	Game design; game complexity; learning goals (no explicit criteria)
9	SeGWADE	Logging of in-game decisions followed by post-game analysis	Learning goals (explicit criteria); player engagement
10	Ter' Aguas	Participant observation; pre-game questionnaire; post-game discussion; interviews conducted 8 months after the game session	Game design; learnings goals (no explicit criteria)
11	The climate game	Pre-game, during-game and post-game questionnaire; participant observation; post-game group discussion	Learning goals (no explicit criteria); game design; player experience
12	Visimple	No information	No information
13	Wastewater RPG	Participant observation	Learning goals (no explicit criteria)
14	Water Safety Plans	Post-game group discussion	Learning goals (no explicit criteria); player experience
15	WATERSTORY	Debriefing sessions	Learning goals (no explicit criteria); game design

For instance, in SeGWADE (#9), learning outcomes were operationalized as closeness to the best solution as reported in the literature, and in Maintenance in Motion (#4), the change in confirmation or rejection of seven different hypotheses related to the Millbrook flooding case was measured. In other games, a generic description of players' learnings was provided as mentioned either by the players themselves or as observed by the game facilitators.

2.5 | FUTURE RESEARCH DIRECTIONS

In this chapter, we reviewed and analyzed 15 serious games for their contribution to 6 decision-making phases and 2 game design phases. Based on the above review and associated analyses, the following directions for improvement of UWM games and future research have been identified.

2.5.1 | Support and include early phases of decision-making

From our review of 15 UWM games, we did not find sufficient evidence that the initial phases of decision-making were explicitly addressed by the game authors. Phase 1 (*Problem structuring*) was covered by 4 games, Phase 2 (*Defining objectives and attributes*) was covered by 3 games, and Phase 3 (*Developing alternatives*) was covered by 4 games. One plausible explanation for the lack of attention on these phases is that information about the early phases of game development process was not provided in the reviewed publications. Another reason could be that games were not explicitly designed to target initial phases of decision-making. This phenomenon is also observed in the software tools designed to support MCDA processes (Mustajoki and Marttunen, 2017) indicating a broader lack of support for early decision-making phases. To better target the initial phases through a game, we recommend using a companion modelling approach (Etienne, 2014) as done in games Ter' Aguas (#10) and WATERSTORY (#15). Using this approach, a workshop can be conducted centered around a role playing game that helps model the complexity of the decision problem by taking the perspectives of different actors into account (Aubert et al., 2018).

Note that by suggesting that games include earlier phases of decision-making, we do not intend to recommend that games must be designed to cover all decision-making phases. Such an attempt will be difficult to achieve as different decision-making phases have different demands. However, even if a serious game is focused on improving the later phases of decision-making, we recommend that the game developers walk through the initial decision-making phases with the target audience and relevant actors, to define an appropriate decision frame and capture the relevant complexities of the real-world problem. This can be done using popular problem structuring methods that can help identify key areas of concern, actors, objectives, alternatives, and uncertainties (Ackermann, 2012; Mingers, 2011; Mingers and Rosenhead, 2004; Rosenhead, 1996).

2.5.2 | Improve game narrative and adaptivity for an immersive player experience

Out of 15 games reviewed only 5 games incorporated story elements such as an introductory narrative or a virtual agent hence there is scope to improve things in this area. As noted by Barab et al. (2007), "we lose interest in a world without story". In their review of 26 educational serious games, Naul & Liu (2019) list down 4 features of effective game narratives: (1) narrative should not be located in one place but distributed throughout the game, (2) strong, relatable characters can help immerse the players further into the story, (3) stories can be made more compelling if they are personalized to the player and respond to their in-game decisions, and (4) linking the fantasy to the learning objective can be useful. These suggestions can provide pointers on how to make a game narrative richer and more immersive.

None of the games reviewed in this chapter were adaptive in nature. A common way to make serious games adaptive is to log and process player data and use virtual agents to intervene when e.g. a player repeats a mistake or is inactive for a long time (Ravyse et al., 2017). Some games reviewed (e.g. #4, 9) already log players' actions for post-game analysis, so using the data to provide dynamic feedback during the game could be implemented. Adaptivity can further be improved by personalizing the game's narrative, scenarios and quests or adjusting the style and strategy of the non-player character using AI (Lopes and Bidarra, 2011). Although AI holds the promise to enhance immersive learning, such high-end software development comes with a trade-off of high computational and development costs. A plausible reason that the reviewed games did not incorporate AI is that associated costs cannot be accommodated in typical research budgets available for serious games that are published in the academic literature (as opposed to entertainment games developed by the game industry).

2.5.3 | Evaluate UWM serious games using controlled experiments and use explicit decision quality indicators

The most common approach used to evaluate changes attributed to the reviewed games was a single group post-test design (7 out of 15 games). This approach, also referred to as a ‘one-shot case study’ has limited scientific value as the observed outcomes of the game intervention cannot be compared to a baseline before the game nor compared to any reference group (Campbell and Stanley, 1963). Single group pre-test/post-test design was the second most common approach and used in 4 out of 15 games. Although this approach is better than a single-group post-test design in that it sets a baseline to which changes after the game can be compared, this experimental design faces multiple threats to internal validity (Campbell and Stanley, 1963; Marsden and Torgerson, 2012). None of the game evaluations reviewed in this chapter applied a qualified experimental design, let alone a randomized experiment or RCT. To the contrary, in the healthcare sector, use of RCTs to establish causality is common practice where a gamified intervention is often compared to a non-gamified intervention (Gentry et al., 2019; Primack et al., 2012). We recommend the water sector to move in that direction to build rigor and better understand the causal effect and added value of serious games for UWM applications. If the aim is to identify which specific element of a game led to the observed change then experimental designs that explicitly isolate and study the impact of the game elements should be preferred to comparison of gamified interventions with non-gamified interventions (Landers et al., 2018).

Regarding the characteristics evaluated in analyzed UWM games, very few games focused on evaluating characteristics other than learning outcomes, i.e. game design, game complexity, player experience, player engagement, and cognition and behavior. Whilst the focus on the attainment of the ‘serious’ part of the game is understandable, game developers should not lose sight of evaluating the ‘fun’ aspects of gaming too. Existing questionnaires (e.g., Ijsselsteijn et al., 2013 and Hogberg et al., 2019), can be deployed to better assess a player’s gaming experience.

UWM serious games should also further benefit by taking into closer consideration state-of-the-art in the field of decision science. Despite aiming to improve decision-making, only 6 games used explicit indicators to evaluate whether the game improved decision-making or not. The decision-maker’s intuitive responses must be checked against ‘evidence’ and the quality of their decisions should be checked against evaluation criteria. To achieve this, decision quality indicators provided by Spetzler et al., (2016) can be used as a starting point. Following these indicators, a few guiding questions to consider while designing game evaluation could be:

- Did the players consider the broader context of the infrastructure-related choices to be made, e.g. climate change adaption opportunities alongside more immediate infrastructure replacement needs?

- Did the game help players go beyond traditional UWM alternatives and come up with new alternatives such as blue-green measures?
- Did players refer to factsheets or future predictions while choosing a UWM alternative or was their decision intuitive in nature?
- What reasoning did players use while choosing between different UWM alternatives? Was there a difference between the reasoning reported pre-game and post-game?

2.5.4 | Incorporate cognitive processes in game design

So far we assumed that the decision-maker is 'rational' and that they can achieve a good quality decision if supported by the correct procedure. However, this does not resemble reality well. Behavioral science shows that cognitive processes significantly influence, if not determine, information processing, judgment and decision-making. Biases and heuristics commonly lead the decision-maker astray from what rational decision-making theory would prescribe. For example, player's decisions are impacted by framing effects of how the set of alternatives are presented or mood states and emotions induced when playing the game (Lerner et al., 2015; Tversky and Kahneman, 1989).

None of the games reviewed in this chapter evaluated cognitive effects of the game. Games aim to create immersive environments that impact people's attention, cognitive and affective processing, in addition to actions or choices within a given framing. Hence, understanding the impact of these aspects on the achievement of the purpose of a serious game with regard to improving decision-making in UWM is a promising future direction. Experiments could be set up to test this impact with potential independent variables being different framings of an alternative, emotions induced at the start of/during a game and dependent variables such as decision quality or engagement indicators.

2.6 | CONCLUSIONS

Planning and management of urban water systems are critical to mitigate the challenges that the future brings: population growth, climate change, and rapid urbanization, to name but a few. Stakeholders in charge of UWM are confronted with complex planning and other decisions that need to be made. Serious games have emerged as a popular tool for decision-making but their current contribution to decision-making and game design processes both remain unassessed. In this chapter, we reviewed 15 serious games that were (a) mapped to common decision-making phases and (b) assessed in terms of game design and evaluation approaches.

The results obtained show that serious games designed for supporting UWM related decisions focus primarily on the later phases of decision-making, while the initial phases, i.e., Phase 1 (*Problem structuring*), Phase 2 (*Defining objectives and attributes*), and Phase 3 (*Defining alternatives*) are not well covered. Although the focus on the later phases is understandable given that serious games are a medium for trial and error in a safe environment, initial phases of decision-making should not be ignored, even if the game is designed to support the later phases. Covering the initial phases well makes sure that the 'right' decision problem will be addressed through the serious game.

With respect to the game design, each game's design elements (Phase 3: *Detailed game design*) and methods used to evaluate the game's impact (Phase 5: *Implementation and evaluation*) were assessed. The results obtained for the game design elements show that UWM games reviewed in this chapter lack elements of (a) backstory and production and (b) AI and adaptivity. Crafting a richer game narrative and making the game response personalized to the player can make these games more attractive and immersive to play thereby providing improved learning gains. Regarding the game evaluation, it was found that single-group post-test research design is the most commonly used approach to evaluate the outcomes of UWM games. Although this approach may be adopted for pragmatic reasons, the results of such an evaluation make it difficult to establish a causal inference between the game intervention and its outcomes. Thus it is recommended to use the RCT instead following research designs proposed by Landers et al. (2018). Other aspects that can be improved in the game evaluation include the use of explicit decision quality indicators to measure the game impact and paying equal focus to the evaluation of both learning outcomes and game experience/design-related characteristics.

The scope of the review conducted in this chapter has its limitations. Since only UWM games targeted at professionals were reviewed in this chapter, the scope can be further extended to cover games targeted at students and general public (see supplementary material in Mittal, Scholten and Kapelan, 2024a for examples). With respect to game design, the findings obtained are limited by the criteria used to evaluate this aspect. The successful game design factors listed by Ravyse et al. (2017) were derived by evaluating edutainment/education games targeted at students at different levels of schooling – primary to college level. In this chapter, it was assumed that the findings from Ravyse et al. (2017) are transferrable to adults/professionals at later stages of brain and personal development and who have higher education levels. The applicability of these factors for serious gaming with adults/professionals needs further investigation beyond the scope of this chapter.

Furthermore, the results obtained apply only to the 15 UWM games reviewed. However, given that mapping of serious games to decision and games design processes is missing in the urban water sector, we hope that that designers and practitioners can gain insights from this review leading to improved design and utility of serious games. It is further speculated that the review findings obtained will be of use to decision-making in sectors other than water. It is worthwhile to conduct a domain-independent review of serious games for decision-making. Further improvement can be made to such a review by including games that are not published in academic journals. Although very limited information was available for these games online, this can be supplemented by conducting interviews with relevant game developers.

Finally, to overcome the gaps identified in the review, the following future research directions and recommendations are made to improve the design and utility of UWM games:

1. Support and include early phases of decision-making through serious games using a gamified companion modelling approach;
2. Create a rich game narrative and adapt the game to the skill, learning ability, and learning needs of the player;
3. Ensure UWM games are systematically evaluated by using explicit evaluation indicators and controlled experiments and
4. Incorporate cognitive processes in the game design and test the influence of behavioral factors such as emotions using a suitable experimental setup.

3

Taming system analysis in serious game design – a methodology combining actor analysis and cognitive mapping

This chapter is based on: Mittal, A., Bekebrede, G., Kapelan, Z., & Scholten, L. (*Manuscript in preparation*). Taming system analysis in serious game design – a methodology combining actor analysis and cognitive mapping.

ABSTRACT

A structured and rigorous systems analysis is crucial for designing a serious game that is able to represent a complex system in a decision-support setting. However, the current literature on game design lacks analytic methods to capture and analyse the real-world system. Often, the choices and decisions made to identify the problem that is considered during the design of a serious game intervention are neither transparent nor reproducible. To bridge this gap, we turn to problem structuring methods, specifically actor analysis and cognitive mapping combined with actor interviews, and present a structured approach for conducting systems analysis for serious game design in this chapter. The methodology helps create individual actor cognitive maps and a combined systems map that can be used to decide the specific problem scope and gaming elements such as roles, actions, events, performance indicators, and rounds. The proposed methodology is demonstrated in an in-depth case study on urban climate adaptation in a Dutch residential neighbourhood where public and private actors thus far have failed to resolve recurrent urban flooding. Our results demonstrate how structured system analysis methods can be used to map the perspectives of different actors and the perceived causality between their preferred actions and goals to achieve a comprehensive understanding of the protracted problem of urban flooding in the case study. For the specific case, we conclude that a serious game focused on co-designing a collective solution and reflecting on the distribution of investment and maintenance costs would seem most appropriate to address the systemic issues in multi-actor climate adaptation.

3.1 | INTRODUCTION

3.1.1 | Importance of revisiting the 'system'

Complex socio-technical systems are everywhere. They can be found in healthcare, manufacturing, transportation, information technology, and water management among many others (Hollnagel, 2012; Soliman & Saurin, 2017). These systems are characterized by "wicked" problems that involve multiple actors, each with their own perspectives, conflicting goals, and key uncertainties about how the future will unfold or other actors might behave (Head & Alford, 2015; Lönngren & van Poeck, 2021; Mingers & Rosenhead, 2004). To support decision-making in such situations, it is critical to first identify and structure a problem by capturing the perspectives of different actors (Ferretti, 2016; Mingers & Rosenhead, 2004; Robin Keller et al., 2010).

Among other methods, serious games are used to support complex decision-making (Kurapati et al., 2015; Slinger et al., 2014). Games are a promising platform to bring actors together and enable cooperation with each other in a simulated reality. By doing so, games can aid understanding of the complexities of the socio-technical system they are representing, the perspectives of other actors involved, and explore the interdependencies between actions and actors in achieving their goals (Duke & Geurts, 2004; Lukosch et al., 2018). Simulation games further allow to simulate system complexity, to enable better understanding and exploration of realistic options and their impact on the status quo (Bekebrede et al., 2015).

Taking the example of serious games in urban water management, we observe that game designers or researchers who use game to support decision processes often start with a pre-defined solution and idea for the game; a proper systems analysis is rarely reported in publications (Mittal, Scholten, and Kapelan, 2022). Most published serious game applications (Aubert et al., 2018; Mittal, Scholten, and Kapelan, 2022; Savic et al., 2016; Zhou, 2014) only provide the design of the game or the evaluation of the effects. Details on what led to the design, why a particular problem scope was chosen, and how the bigger picture was developed are often overlooked (Mittal, Scholten, and Kapelan, 2022). In other words, an overview of the choices behind the "system" being addressed in the game is generally missing in the applied serious gaming literature. However, to make sure the 'right' problem or dilemmas are discussed, a thorough understanding of the system is needed, next to well-defined boundaries to connect the game outcomes with the real-world system.

According to the triadic game design philosophy, it is critical to balance three equally important worlds while designing a game – Play, Meaning and Reality (Harteveld, 2011; Harteveld et al., 2010). Reality relates to the world of the subject-matter experts, the client and the different actors and perceptions involved in identifying what real-world problem needs to be addressed. A good systems analysis captures, structures, and visualizes parts of the real world that are relevant to the initial problem framing before the game is designed and implemented. This ensures the development of a valid simulation game, one which represents and meets the designed-for objectives (Peters et al., 1998). Bringing the focus back to the 'system' is important to ensure that the game addresses the 'right' problem.

3.1.2 | Gaps in game design frameworks

One of the earliest framework on the serious game design process was put forward by Duke (1974)outlining 9 steps - starting from the problem statement to the final game product and its evaluation. Since then, there have been further adaptations to the framework, reducing it to 4 phases as in Peters & Westelaken, (2014),or 7 steps as in Lukosch et al. (2018). While there are other frameworks that focus on game design philosophy (Cunningham et al., 2014; Harteveld, 2011; Harteveld et al., 2010; Schell & Safari, 2020), a specific step in the design process such as game conceptualization (Björk & Holopainen, 2005) or game development and structuring (Hunicke et al., 2004; Walk et al., 2017; Westera et al., 2008; Winn, 2009), hardly any frameworks focused on the step of analysing and simulating reality in a structured way. Hence, for this article, we simplify the game design process into 5 phases (Mittal, Scholten, and Kapelan, 2022): 1. Design Specifications, 2. Systems Analysis, 3. Detailed Game Design, 4. Game construction, Testing and Validation, 5. Game Implementation and Evaluation, and focus on gaps concerning phases 2 and 3.

Given an initial problem specification, Phase 2 focuses on systems analysis for understanding the real-world system and identifying relevant actors and key elements that represent the real-world system along with the interrelationships between them. To do this, it is recommended to collect information about the real-world system through interviews or desk research (Peters & Westelaken, 2014). The information collected is then clustered into meaningful categories and relationships to come to an overall conceptual "schematic" which represents the system including the focal issue/problem of interest in a simplified way. In this phase, the general principles of reduction and abstraction apply, however, there is limited guidance on structured ways to do so in practice, requiring the designer to rely on intuition and experience. We consider this an important gap in serious game design for two reasons. Firstly, it is prone to biases resulting from the judgmental and choice processes of the designer when conducting the systems analysis. Secondly, it lacks transparency about the choices made regarding which elements and interactions from the real world to include in the game. The consequence of this not only means that the judgment and choices are hard to reproduce, but also that an invalid representation of reality may result.

The information gathered from the systems analysis sets the foundation for the choices in the third phase (Detailed Game Design). For Phase 3, a selection of the most relevant system components needs to be made to determine which aspects of reality to represent in the game. This forms the basis to populate the "matrix of system components and gaming elements" (hereby referred to as the game matrix) wherein the chosen system components are mapped to gaming elements such as playable roles in the game, their actions, resources, goals, events etc. (Peters & Westelaken, 2014). However, the process of translating the information gathered in Phase 2 to the systems matrix in Phase 3 is not detailed in the existing literature, highlighting another gap in current practice and literature which (over) relies on the intuition and experience of the game designer to interpret and execute the intermediate steps. To address this, we propose to map the analysis and outputs of the systems analysis developed in Phase 2 to the game matrix elements. Addressing these gaps can further contribute to Phase 4 by supporting game validation and making underlying choices and assumptions transparent and potentially lead to more valid and impactful games in Phase 5.

3.1.3 | Proposed contribution and outline

To establish a structured process for system analysis in game design, we turn to policy and decision analysis, wherein problem structuring is usually the first step in analysing any multi-actor issue (Mingers & Rosenhead, 2004). The use of these methods for designing games is still nascent. Although systems mapping is recommended for game design, there is a lack of awareness and demonstrable examples of how to conduct this in practice. Eden & Smithin (1979) used cognitive mapping as the basis for designing an operational computer game. However, their methodology does not describe the links between the cognitive mapping and the game design process and how the outputs of the map were translated into game elements. In another study, Müller et al. (2022) used visual systems mapping to exchange of domain knowledge within an interdisciplinary team of game designers. Causal maps of different parts of the system were created by the design team and combined into a larger systems map. However, no actor analysis was conducted and the perceptions of real-world actors were not elicited nor systematically taken into account in their mapping. Therefore, the aim of this chapter is to develop a structured approach, one that is rooted in the perceptions of real-world actors, for conducting systems analysis for serious game design.

Based on the review of the literature and identified gaps, we propose a new methodology that combines actor analysis and cognitive mapping to perform a structured systems analysis for serious game design that is both transparent and reproducible. The rationale behind combining these methods is that actor analysis helps identify relevant actors and cognitive mapping captures the perceived causality and allows visual synthesis and analysis of the information gathered from interviewing the actors. We initiated Phase 1 of the game design process by using an initial game design specification from a real-world case study problem without diving into typical decisions in Phase 1 such as target group, time to play, deadlines and resources, etc. These aspects set boundaries for the design, but not on the analysis of the system. Since game design is not a linear process, these aspects can be discussed after the analysis of the system. The focus of the chapter lies on demonstrating a detailed and structured analysis of the real-world situation through Phases 2 and 3. The analysis is conducted from the perspective of the game designer gathering inputs from real-world stakeholders and synthesizing them into a conceptual map for further game development. We expect that our systems analysis approach would lead to a more valid and transparent representation of the real-world problem in the game. However, demonstrating and testing for better validity of the game by conducting Phases 4 and 5 is outside the scope of this chapter.

The proposed systems analysis methodology is presented in Section 3.2. In Section 3.3, we introduce the case study context and the specific methods used to execute the methodology. We demonstrate the application of the methodology to a real-world case study on urban climate adaptation to mitigate flooding in a Dutch residential neighbourhood in Section 3.4. In Section 3.5, we share our reflections on the findings as well as the strengths and limitations of the methodology in supporting game design and end with our main conclusions for serious game designers in Section 3.6.

3.2 | SYSTEM ANALYSIS METHODOLOGY FOR GAME DESIGN

Our proposed methodology is presented in Figure 3-1, which focuses on conducting a systems analysis (Phase 2) and translating the outcomes into game design (Phase 3). For a good problem analysis of the situation it is important to not think in games or game concepts in Phase 2 as this can frame the analysis of the real-world system (Duke & Geurts, 2004). Whereas games are versatile and can address many challenges, not all problems lend themselves to being addressed by a game, especially those that require a perfectly rational response to complexity with data-rich and mathematically correct solutions (Harteveld, 2011).

Starting from an initial problem description and game requirements that either come from a client or a research question in Phase 1, we recommend starting Phase 2 with an actor analysis to identify actors relevant to the real-world problem. An actor analysis begins with preparing an inventory of actors involved in the problem and determining their objectives, values, resources, and their formal role (if any) in the policy network – formal tasks or legislations that govern their actions. This process usually results in a long list of actors. A ‘Power-Interest (PI) Grid’ is then developed to distinguish actors into four categories based on their power (resources to influence) and interest (stake or involvement) (Bryson, 2004; Enserink et al., 2010; Johnson et al., 2008): Players (high power, high interest), Context Setters (high power, low interest), Interested Subjects (low power, high interest), Crowd (low power, low interest). Typically, those classified as “players” are considered for further analysis.

The next challenge is to understand an actor’s thoughts about a problem, their own objectives within the problem context, its causes and consequences, along with possible solutions and their own available or preferred actions. Cognitive mapping is particularly insightful, as it allows the game designer or the decision analyst to map the relationships between issues and actions to outcomes and goals and thereby make the perceived causal (inter)dependencies within individual actor perceptions more explicit. Comparison of the individual cognitive maps or their amalgamation into one aggregated map can explain the reasons behind the action or inaction of certain actors, and uncover conflicts of interests, dilemmas and resource dependencies while aiding the identification of potential for cooperation and collective action (Cunningham and Hermans, 2018).

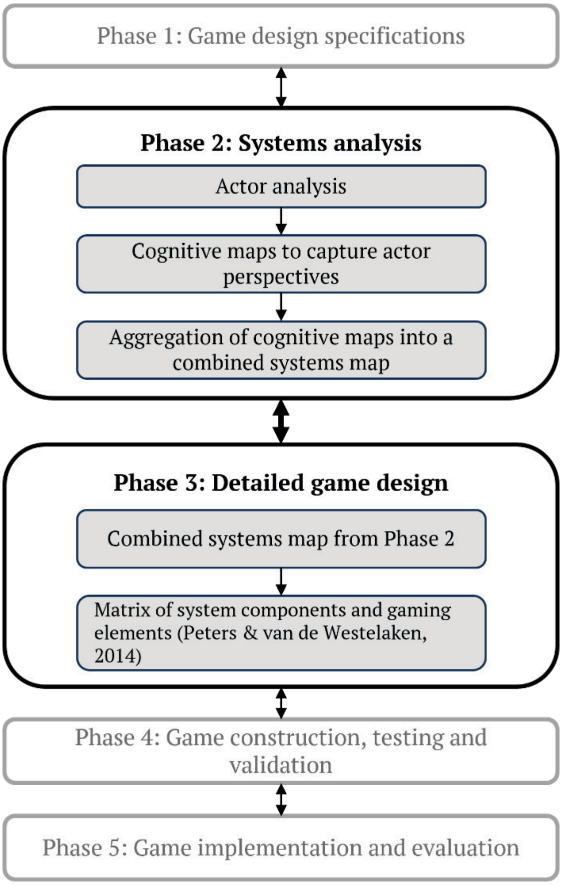


Figure 3-1: Proposed process/methodology for conducting systems analysis as part of the game design process

Cognitive maps are hierarchical in nature where the structure of the map takes the form of a means/ends graph with goals at the top of the map (Eden, 2004). A basic cognitive map is presented in Figure 3-2, with "actions" to solve the problem, "goals" reflecting actor objectives, "context" describing perceived context uncertainties outside of the control of the actors, and "system factors" representing the intermediary concepts that link the actions and context uncertainties to goals (Cunningham & Hermans, 2018). These variables are connected using arrows that indicate causality; a variable at the tail of an arrow is a means to achieve the variable at the head of an arrow (Ackermann & Eden, 2011). Usually, plus and minus labels are used to further denote the direction of causality, a "+" sign between variable A and variable B implying that an increase in A will lead to an increase in B. On the other hand, a '-' sign implies that an increase in variable A will lead to a decrease in variable B.

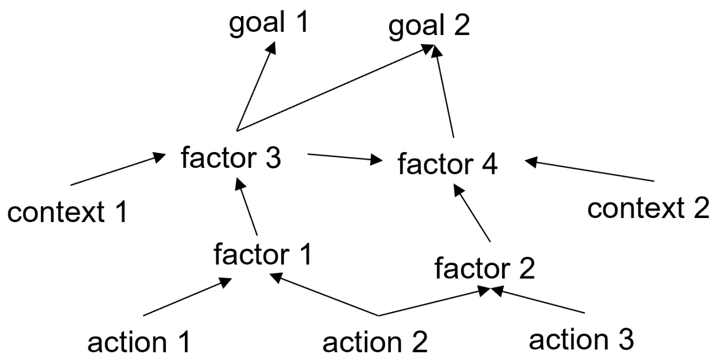


Figure 3-2: An abstract representation of a cognitive map (adapted from Cunningham and Hermans, 2018)

To capture the perspectives of actors identified from actor analysis, cognitive maps of each actor can be made and aggregated into a combined systems map (CSM) representing the actors' goals, actions, perceived causality and uncertainties. This CSM provides the 'schematic' of the system under study and gives an overview of the systems and insights into its complexities and dilemmas. Complimentary analyses and comparisons of the obtained maps provide further essential information to develop the game matrix. Based on the CSM, game designers and clients can consciously define the boundaries for the next game design steps. More details are presented in the Methods section.

In Phase 3: Detailed Game Design, we propose using the CSM generated in Phase 2 as the basis for obtaining the information required to populate the game matrix. The actions, factors, context and goals from the CSM are a starting point to identify game elements such as roles in the game, actions, goals, and events. We demonstrate this translation with a few examples in the Results section.

3.3 | TESTING APPROACH FOR THE PROPOSED GAME DESIGN METHODOLOGY

3.3.1 | Case study context: Urban flooding in the Netherlands

As the impact of climate change increases, cities across the world need to proactively adapt to cope with the growing frequency and severity of intense rainfall events. Increasing urbanization is leading to more paved cities which reduces storage, infiltration and evapotranspiration of stormwater. As a result, this water runs off from surfaces and needs to be drained via underground sewers. With increasingly strong rainstorms, these discharge events exceed the capacity of the underground sewers, leading to flooding in urban areas.

For this research, a case study was used to test and apply the methodology proposed in Chapter 2. The case study area is a neighbourhood of 170 households spanning 2.3 hectares in the historic centre of a densely populated city in the Netherlands (see Figure 3-3). It was chosen as it is a good representative example of flooding in urban areas and there is an ongoing pilot project in the area to upgrade the current infrastructure and discuss possible solutions by bringing actors together. The built environment in the neighbourhood mostly consists of residential houses surrounded by canals, with most of the houses having municipal monument status. This implies that the houses are considered as protected entities for their beauty and cultural and historic value and cannot simply be demolished or renovated without permission from the environmental agencies. Most of the public spaces are covered with roads and pavements.

Figure 3-3: Case study schematic. The legend shows the age of the current underground sewer pipe infrastructure

The majority of current sewer infrastructure lies underground in a narrow back alley that runs across the neighbourhood (see the red lines in Figure 3-3). It is more than 150 years old and leaking. The remaining parts lie under the public roads in front of the houses (see the blue, green and yellow lines in Figure 3-3). The sewer system is a combined system collecting both stormwater runoff (rainwater that flows off from roofs and surfaces) and sanitary wastewater (from households, incl. bathrooms and kitchens), which is pumped to the wastewater treatment plant for processing. Additionally, the case study is situation in a low-lying area with accompanying groundwater issues. Low groundwater levels put the wooden foundations of houses at the risk of rotting while high groundwater levels can flood the basements and gardens. Historically, the sewer system was designed as a bulged system (also called "polderriool" or "opgeboied" system in Dutch), which was used to convey wastewater and regulate groundwater in low-lying areas. A bulged sewer system is one in which a section of the sewer is always filled with sewage, preventing the entering of groundwater in sewage pipes. However during intense rainfalls, the capacity of the sewer and pumping station is insufficient to convey water, causing flooding. Given this situation, the neighbourhood experiences frequent and severe flooding to a level that requires interim measures like sandbags in the doorway to prevent water from entering the houses, typically twice a year. Currently, public and private actors have different actions at their disposal. Although it is clear that these actors need to align measures to prevent flooding, they have thus far failed to do so.

In this study, researchers collaborated with an engineering consulting company that had been commissioned by the municipality to study possible technical solutions to address household flooding in the analysed area. A data sharing agreement was signed between the 3 parties to ensure safe data sharing, privacy, and ethical concerns. The company was expected to engage and consult with local residents with the aim to ensure their acceptance of these solutions. The situation in the case study at the point of TU Delft joining the collaboration constituted the starting problem description and the game specifications for this project. One of the tasks of the consulting company was to engage and involve citizens in the case study area. A group of residents termed as "sounding board" had been setup in the neighbourhood to start discussing the technical solutions proposed by the company. A serious game was further considered as a potential means to engage citizens.

Before diving into the game design problem analysis was undertaken to understand the technical and multi-actor decision-making perspectives that could inform a stakeholder engagement approach through the serious game. The purpose of the analysis was not to create a participatory co-design space for game development, rather to analyse the problem context and arrive to a suitable problem scope could be used for further game development. This was done to ensure that if a game was developed after the outcomes of the problem analysis, it would be effective and relevant to the actors involved. Hence, the methodology proposed in Section 3.2 was applied to conduct Phases 2 and 3 of the game design process. When doing so all stakeholders were considered as research participants and analysed (including consultants). The consulting company provided suggestions for people who could be contacted for interviews.

3.3.2 | Actor analysis: Identifying relevant actors to interview

The issue of local flooding was used as the starting problem scope for the actor analysis. An initial list of actors was prepared by reviewing the formal roles and responsibilities of actors across five governance levels (European to neighbourhood level, see list in Supplementary material A in Mittal et al., 2024b). This list was then discussed with the consulting company to ensure all important actors were included in the analysis. Figure 3-4 shows the list of relevant actors from the case study mapped onto the PI grid. Four actor groups with high interest and high power emerge from the map– the municipality, residents living, the engineering consulting company, and the water board.

The municipality consists of various departments with different interests, roles and responsibilities. For this study, the most important actors are the civil engineering department and the Monuments department ("Monumentenzorg" in Dutch). The former is in charge of all municipal civil engineering works, including sewer infrastructure and roads, and the Monument department oversees the protection of heritage infrastructure. The municipality is the key governmental actor responsible for the collection and drainage of stormwater from the public-owned land along with the collection and transport of sanitary wastewater to the wastewater treatment plant (WWTP) (The Ministry of the Interior and Kingdom Relations, 2024).

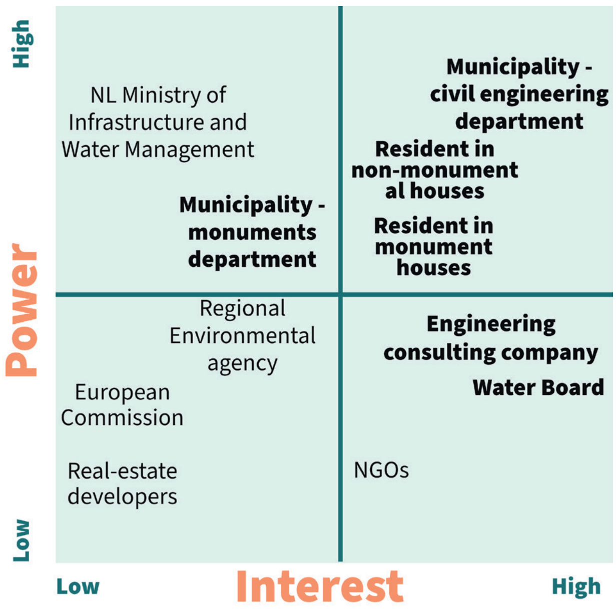


Figure 3-4: Power-Interest grid of actors

Residents bear the responsibility for stormwater management of their private properties (Dai et al., 2018). They can install blue-green solutions or sustainable urban drainage solutions (SUDS) (CIRIA, 2015) in their private space to store, convey and infiltrate stormwater or connect to the public infrastructure (the common situation). In the case study area, residents primarily live in two types of houses – monumental and non-monumental houses. Monumental houses have added restrictions and requirements for permits to make any changes to the house. Since the issues and challenges of the two types of residents are different, we distinguished the two during further analysis.

The Regional Environmental Agency enforces regulations set by the Monuments department, focusing on compliance with environmental regulations and granting permits for housing and construction work. They provide the permits and licenses for making changes to monumental houses in the case study area. Although these actors have considerable interest and power in the situation, especially the Monuments department, we could not access their representatives for an interview and hence, their detailed perceptions were not taken into account for further analysis.

The water board is primarily responsible for managing the level and quality of surface water which includes wastewater treatment at centralized wastewater treatment plants (WWTPs) before discharging the treated wastewater back into the environment (typically surface water bodies like canals, rivers etc) (OECD, 2014). Five actors with high interest and power: municipality – civil engineering, water board, engineering consulting company, and residents in non-monumental houses and residents in monumental houses were interviewed and their perception about the problem of urban flooding was analysed further.

3.3.3 | Interviews and building actor-level cognitive maps

Semi-structured interviews were conducted following Cunningham & Hermans (2018). The interview protocol – the introductory text and the questions, were carefully designed to focus on understanding the perspective of the interviewee about the urban flooding. The questions progressed from the identification of problems to goals, actions, causality between actions and goals, and external variables (see supplementary material B in Mittal et al., 2024b). Great care was taken to ensure that no unfair expectations are raised about the outcome of the serious game. Only towards the end of the interview, interviewees were asked if they would be willing to play a serious game on this issue of urban flooding and what elements they would like to see included in such a game.

The selection of interview participants followed a two-step approach. The initial interviewees were recruited via the contacts of the consulting company. An email was sent out to a resident group in the neighbourhood who actively meets to discuss neighbourhood issues and members of the municipality. The email presented the research's aim and invited participants for an interview. Further, a snowball sampling technique was employed to expand the participant pool (Reed et al., 2009).

In total 8 interviews were conducted, seven in person and one online, following the guidelines by Jacob & Furgerson (2012). Informed consent procedures were adhered to when collecting data from human participants and these were reviewed and approved by the TU Delft Human Research Ethics Committee (approval nr. 3287, see supplementary material C in Mittal et al., 2024b). Each interview lasted for an approximate duration of one hour and a voice recording was made to create a detailed transcript. Qualitative top-down coding was used to categorize and extract relevant information from the interviews (Bryman, 2012), using the software Atlas.ti (ATLAS.ti Scientific Software Development GmbH., 2024). Each interview transcript was first read to identify the boundary/end points of a cognitive map – “goals”, “actions”, and “context factors”. Thereafter, the interview text was read in detail to identify “causal factors” that explain the causality between goals, actions and context variables.

The list of identified variables were then transferred into the diagrams.net software (Alder, 2024). To represent measurable quantities, for which one could meaningfully say that they can increase or decrease in value (Enserink et al., 2010), all variables were denoted as a noun phrase. For goal variables, the desirable change in the goals (as expressed by the interviewee) was denoted in brackets either as increase (inc), decrease (dec), no change (nc), not increase (not inc) or not decrease (not dec). The variables were added to a blank sheet in diagrams.net and causal links were made, starting from the actions to causal factors to goals, then contextual factors to causal factors to goals. The causal links were each given a sign depending on the correlation between the two factors it connected. The interview text was used as a basis to make the connections wherever causality could be deduced and the missing gaps were filled in by the first author. For further guidelines on preparing cognitive maps, refer to (Cunningham & Hermans, 2018; Eden, 2004; Enserink et al., 2010)

One cognitive map was developed per interview and further merged into one map per actor group. This was done to convey the viewpoint held by specific actor groups rather than individual interviewees' perceptions. To streamline the aggregation of the maps across similar actors, we began with the most detailed map and progressively added missing variables and causal relationships from other maps. Where causality was unclear, it was internally validated by subject matter experts in the team to ensure the logic of the underlying physical system is accurate. To enhance the specificity of the mapped elements, we kept more informative phrasing such as “household costs/maintenance costs of sewer pipes,” compared to “costs”. Furthermore, hierarchies between goals were established and maintained. For example, "aesthetics of inner city [inc]" was a fundamental goal in one map and as a means to achieve the goal of "monumental value of the inner city [inc]" in another; thus, we kept the latter's more specific hierarchy.

An internal validation process was undertaken within the research team wherein the cognitive maps made by the first author were validated by the last author, who was not involved initially in the development of these maps, to check for logic and correct application of the rules of making cognitive maps. Figure 3-5 shows the translation of individual interviews into the five resulting actor-level cognitive maps.

To streamline the aggregation of the maps across similar actors, we began with the most detailed map and progressively added missing variables and causal relationships from other maps. To enhance the specificity of the mapped elements, we kept more informative phrasing such as “household costs/maintenance costs of sewer pipes,” compared to “costs”. Furthermore, hierarchies between goals were established and maintained. For example, "aesthetics of inner city [inc]" was a fundamental goal in one map and as a means to achieve the goal of "monumental value of the inner city [inc]" in another; thus, we kept the latter's more specific hierarchy.

3.3.4 | Aggregation of actor perspectives into a CSM

To obtain an overall picture of the system, the actor-level maps were further aggregated into a CSM as shown in Figure 3-5. The process of aggregating maps across actors was similar to the aggregation of cognitive maps for similar actors as described above. To consolidate the grouped actor maps effectively, a crucial step involved conducting a consistency check across all maps to identify and rephrase similar variables. We made a list of variables from all the maps and got rid of duplicates by making sure similar factors were phrased the same way. For instance, if a variable was about how things look, similar variables such as "aesthetics of the area" or "aesthetics of the inner city" were reduced to a consistent and more detailed phrasing "aesthetics of the inner city”. This process reduced the number of variables from 256 to 160.

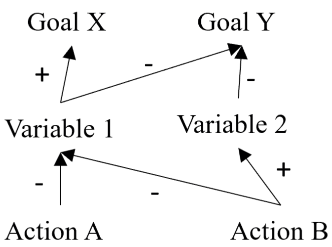
Within the 160 unique factors, a frequency count was done to identify the most frequently occurring variables. As a rule of thumb, variables with a frequency count from three to five (given a maximum of five actors) were first added to a blank map, incrementally adding actor-level maps to the overall map. Here, we were attentive to variations in meanings, i.e., goal, means, context or system factor, attached to the variables as per the different actor perspectives. For instance, a variable might be mentioned as an external influence by one actor and as a means to achieve a goal by another. This implies that actors perceive different boundaries to the problem (Pluchinotta et al., 2022). In such cases, the system boundary was made bigger and re-interpreted as now all the variables under the control of the five actors were considered part of the system.

3.3.5 | Analysing the cognitive maps

Individual cognitive maps

To analyse the maps of different actor groups, we assessed the presence of dilemmas in the maps of different actors. To implement this, an action-goal consequence table was created for each actor, recording the direction of causality of each action-goal path as shown in Figure 3-6. For an uneven number of negative signs, the resulting causality is negative ('-', action A and action B reduce the level of goal X), while an even number results in a positive sign ('+', action A and action B increase the level of goal Y). When multiple causal paths exist with incongruent signs, then the relation is undetermined (denoted as '+/-' as between action B and goal Y). Quantification of the impacts would be required to determine the resulting overall sign.

Actions may have effects on more than one goal, which may furthermore be conflicting, resulting in a dilemma concerning what action to take. Analysing the consequences tables of each actor can surface action dilemmas faced by the actor. For instance, if the actor wants an increase in goals X and Y, and action A leads to a decrease in X but an increase in Y, then the actor faces a dilemma. For each action in the cognitive map, we determined whether the action leads to a dilemma for the actor.



Goals → ↓ Actions	Goal X [inc]	Goal Y [inc]
Action A	-	+
Action B	-	+/-

Figure 3-5: Example of an cognitive map and a corresponding action-consequences table

The actor maps were further compared to understand the similarities and differences in perception of the system as well as conflicts in terms of goals and actions (Cunningham & Hermans, 2018). Different perceptions often explain fragmented or misaligned actions that maintain rather than resolve system problems, whereas similar perceptions aid coalition forming and cooperation. We checked for and counted the similarities across the actors' system maps, i.e. the number of similar variables across maps. Similarly, we also analysed goal conflicts – when actors desire different directions of change in the same goal and action conflicts – when the same action leads to desirable consequences for one actor and undesirable for another.

Combined systems map (CSM)

The CSM was analysed by looking for the map structure, thematic clusters as well as influential variables. Examining the inherent characteristics of the map, like its structure, provides valuable insights into the complexity of the depicted issue. For instance, a map with a notable number of "heads" (goal statements) suggests an awareness of and concern for addressing various, potentially conflicting objectives.

A CSM can be further broken down into clusters to uncover emerging themes. The goal of identifying these groups is to recognize sub-problems or a system of problems that contribute to the bigger issue at hand. At one extreme, the CSM may have islands of disconnected clusters and at the other, the map may be highly interconnected. Typically, for complex systems, a map cannot be broken into disconnected clusters. Looking at emerging clusters may be required, which when summarized through a descriptor, reveals a relatively distinct aspect of the issue that can be addressed somewhat independently of other parts.

To pinpoint the most linked variables in a cognitive map, we focused on nodes with a considerable number of arrows directed towards or away from them. These nodes are likely to represent the most influential or critical variables within the map.

3.3.6 | Translating the CSM into game design elements

The outcomes of the system analysis are the starting point for conceptual game design (Phase 3). The CSM can be used to give feedback to the problem owner and discuss whether it is a good representation of reality and whether the boundaries are adequate. Together with the problem owner, a more specific problem scope and boundary (i.e., a part of the CSM) of what the game should focus on can be selected for further translation into game design. The selected problem scope can be further translated to game elements as shown in Table 3-1.

Table 3-1: Mapping the CSM to the common game elements. Wherever definitions of game elements in the literature could not be found, the authors came up with their own working definition for the scope of this chapter.

Common game elements (inputs for game design)	**Brief definition of the element**	**Deducible from the proposed methodology?**	**How does CSM analysis help with deducing the game element?**
Problem scope	The specific issue and boundaries that will be addressed in the game.	Yes	Part of the CSM that is chosen as the focus and boundary for the game design in consultation with the client
Objective of the game	The larger/general objective of the macro cycle of the game design intervention (Klabbers, 2018). For instance, educating the players about a certain topic.	Yes	The thematic cluster that defines the chosen scope within the CSM
Objective in the game	The specific objective in the micro cycle of the gameplay (Klabbers, 2018). For instance, maximizing profit or avoiding a certain number of floods	Yes	Fundamental or sub-goals in the selected scope
Scenario	The storyline – history and the present situation that sets the context and background for the game and brings all players to the same page (Duke & Geurts, 2004)	Partly	The chosen problem scope in the CSM can provide the current scenario and the future goals but more information of the history of the problem would need to be added to develop a scenario
Events	Random or scheduled events that occur during gameplay providing players with a challenge to overcome (Duke & Geurts, 2004)	Yes	External variables in the chosen problem scope and variables/actions by actors outside the chosen problem scope
Roles	Hypothetical set of characters, positions, interests, knowledge and responsibilities assigned to a player (Duke & Geurts, 2004)	Yes	Actors in the chosen problem scope
Shared goals (in the game)	Specific goals that players much achieve together as a group.	Yes	Shared concepts/similarities analysis of CSM
Rules	The inner formal structure of games (Tekinbaş, 2003). They lay down constraints on what the players can and cannot do, sequence of actions and interaction among players, winning and losing conditions, etc. (Charsky, 2010)	Partly	How the actions of players affect their and the goals of other actors. Prior actor analysis (see for instance supplementary material A) can be used to deduce formal rules and regulations and organizational hierarchies that impact interactions of actors/players

Common game elements (inputs for game design)	**Brief definition of the element**	**Deducible from the proposed methodology?**	**How does CSM analysis help with deducing the game element?**
Rounds	Sequence of gameplay in which players take turns to perform, after which the game state is updated and a new round begins	Partly	Linked to external variables and progression through time and the causality that the map reveals
Scoring indicators	Criteria or indicators that provide feedback to players on their decisions and are used to track their progress through the game (Duke & Geurts, 2004)	Yes	Operationalization of fundamental or lower-level goals in the chosen problem scope
Feedback	Information that players receive from the game (linked to scoring indicators) that helps them understand their performance and adjust their strategy	Partly	Qualitative causality can be inferred from the CSM. Quantitative modelling will be required for the assessment of the impact of actions on goals
Individual goals (in the game)	Specific goals that each player must achieve based on their role.	Yes	Goals from the actor-level cognitive maps
Actions	Specific decisions players take during the game	Yes	Actions of actors in the chosen problem scope. Actor-level dilemmas can be deduced from individual actor cognitive maps, goal and action conflicts from comparisons and overall CSM.

Figure 3-6: Cognitive map of the municipality

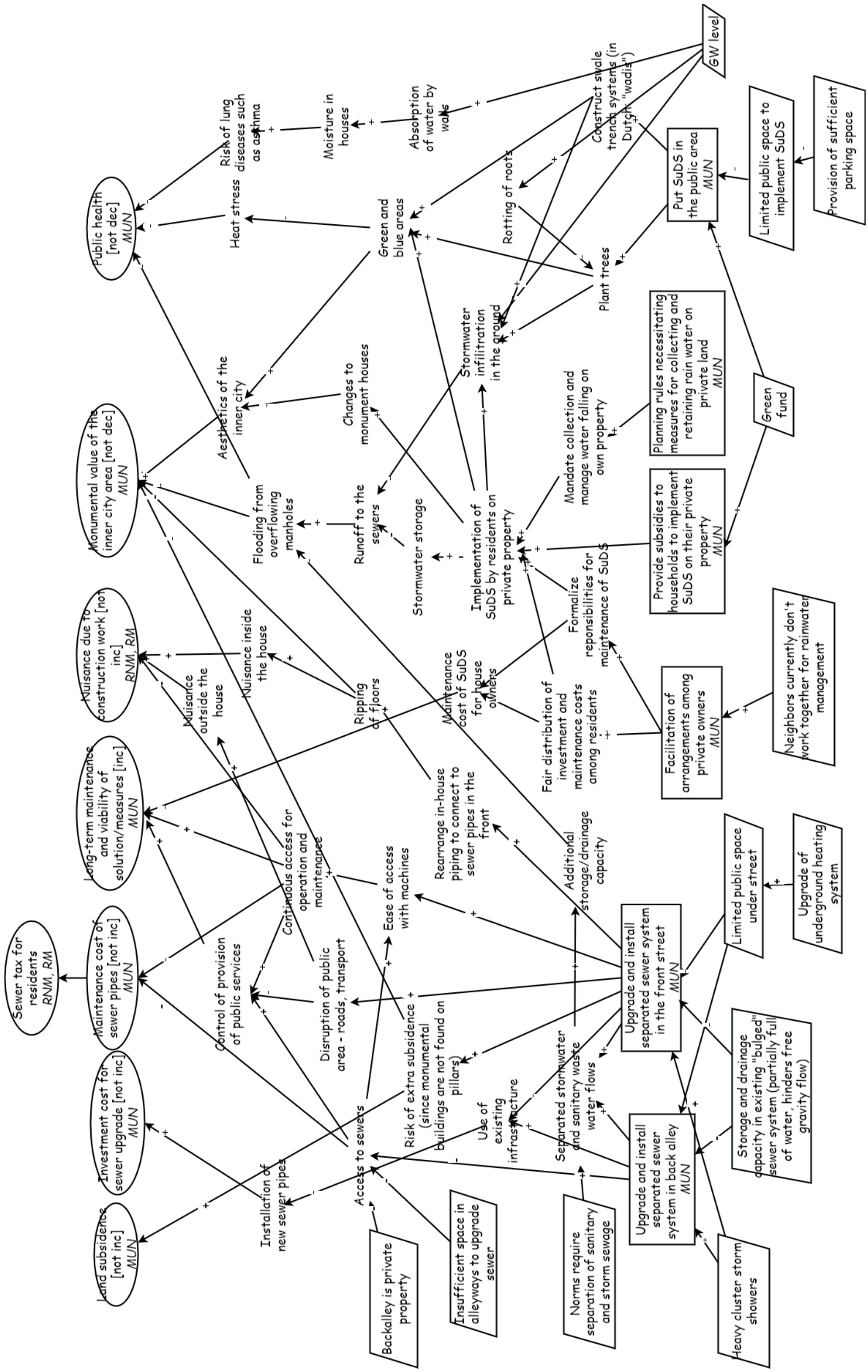
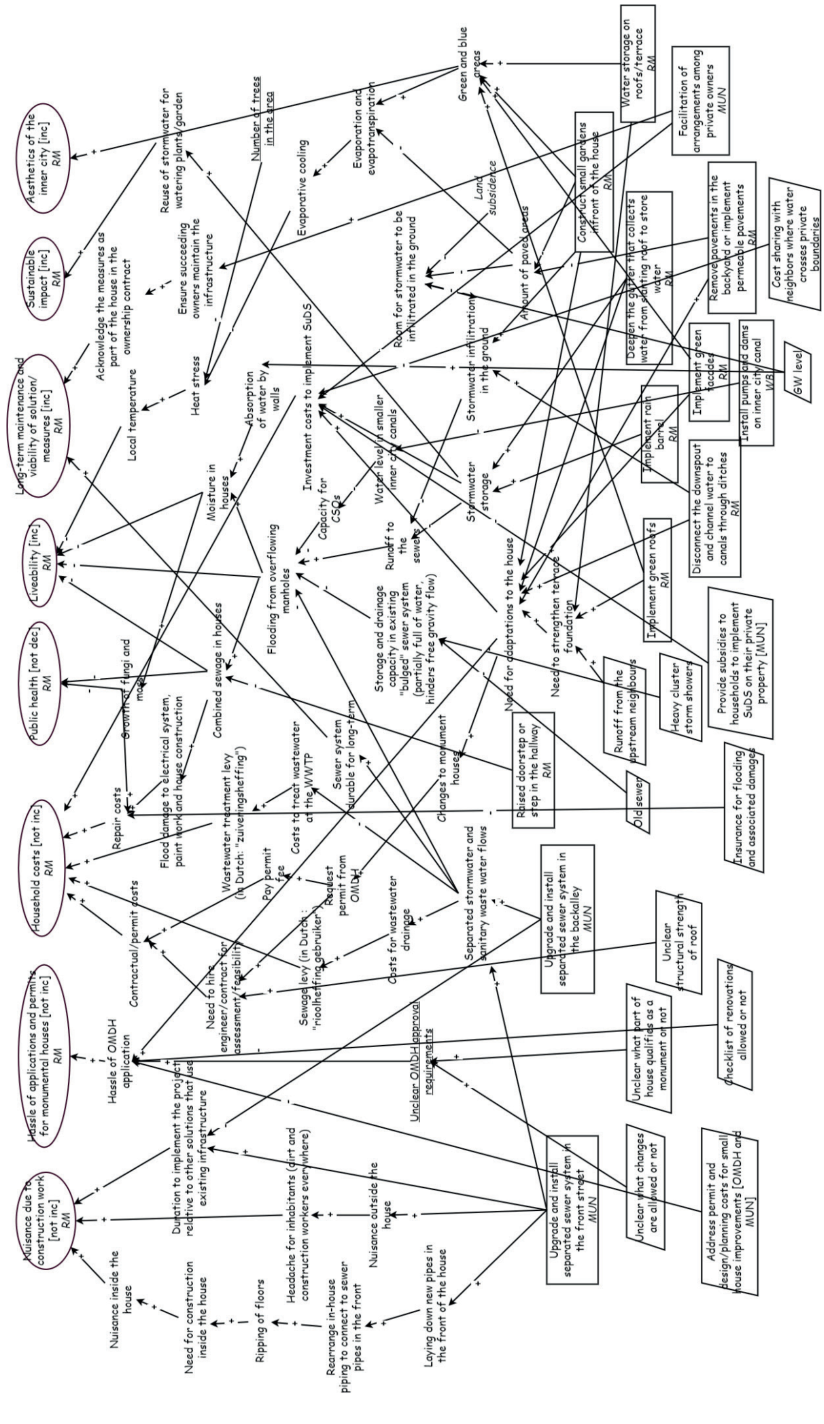


Figure 3-7: Cognitive map of the resident monumental house



3.4 | RESULTS

3.4.1 | Individual cognitive maps

In this section, we present the cognitive maps developed for actors identified as critical in the previous section. We illustrate how to read the cognitive maps and identify actor dilemmas from the action-goal tables taking the municipality and resident monumental house as examples. Cognitive maps of the water board and the residents of non-monumental houses can be found in supplementary material D in Mittal et al. (2024b).

Figure 3-7 and Figure 3-8 shows the cognitive map of the municipality and residents of monumental houses. The goals are marked in ovals at the top, actions are highlighted at the bottom in rectangles and the external factors are presented in parallelograms at the bottom and periphery. Following one of the causal links from an action to a goal in Figure 3-7, i.e., from the bottom to the top of the map, the municipality perceives that taking the action "upgrade and install separated sewer system in the back alley" would decrease "access to sewers", leading to higher "maintenance costs of sewer pipes" in the long run. Access to sewers is further hampered by factors that are outside the municipality's control, i.e., there is "insufficient space" to upgrade the sewer and part of the alley is "private property".

Comparing the municipality and the resident monumental house cognitive maps, we see that both actors have some shared and individual goals. While the municipality is concerned with goals like "land subsidence", "investment" and "maintenance cost for sewers", "monumental value of the area" and "public health", the residents are concerned about "household costs", "liveability", "sustainable impact", "nuisance due to construction work" and "hassle of applications and permits for monumental houses". Both actors however want that "long-term maintenance and viability of the solution (to flooding)". Similarly, these actors have different actions at their disposal. The municipality can either take actions in the public space – upgrade sewers or put SUDS or take more policy/planning initiatives in terms of provision of subsidies or facilitation of arrangement among private owners to incentivise the implementation of SUDS on private property. The residents on the other hand can mostly implement SUDS on their private land.

Actor dilemmas

In this section, we present the actions-goals consequences table for the case study actors that can help deduce dilemmas faced by each actor. These dilemmas help identify actions and goals of an actor that are critical to include in the game as they create the need for the player to trade off one objective against the other. Inclusion of these actions and goals can help the player understand the consequences of an action on conflicting objectives.

Table 3-2: Action-goal consequence table for the municipality-civil engineering. Signs represent the overall impact of the action on the goal (+ meaning increase and – meaning decrease). Actions that lead to desirable consequences on criteria are marked in green, undesirable consequences are marked in red, and uncertain consequences are marked in yellow

Goals→ **Actions ↓**	**Land subsidence [not inc]**	**Investment cost for sewer upgrade [not inc]**	**Maintenance cost of sewer pipes [not inc]**	**Long-term maintenance and viability of solution/measures [inc]**	**Monumental value of the inner city area [not dec]**	**Public health [not dec]**
Upgrade and install separated sewer system in back alley [MUN]		-	+	-	+	+
Upgrade and install separated sewer system in the front street [MUN]	+	+	-	+/-	-/-/+	+
Facilitate arrangements among private owners [MUN]				+/+	+/-/+	+
Provide subsidies to households to implement SUDS on their private property [MUN]					+/-/+	+
Planning rules necessitating measures for collecting and retaining rain water on private land [MUN]				-/+		+
Put SUDS in the public area [MUN]					+/-/+	+

The action-goal consequences table of the municipality is presented in Table 3-2 and the tables for other actors can be found in supplementary material E in Mittal et al. (2024b). Comparing the sign of the impact on the goal with the desired change we see that one of the municipality actions “upgrading and installing the sewer system in the front alley” leads to a dilemma for the municipality as it would lead to high investment and maintenance costs and less long-term viability of the solution (which is contrary to the desired change) while leading to an increase in monumental value and public health. Similarly, the action "Upgrade and install a separated sewer system in the front" also leads to a dilemma.

Coming to other actors, residents living in monumental and non-monumental houses perceive a common dilemma as actions requiring changes to their private property such as the implementation of SUDS would likely increase their "household costs" but lead to positive outcomes on other goals such as "sustainable impact", "liveability", "aesthetics of the inner city" and "long-term maintenance and viability of the solution". For residents living in monumental houses, an additional goal - "hassle of applications and permit for monumental houses" reinforces the dilemma as making changes to their private property requires permits from the REA.

The consultants do not perceive a dilemma. Based on their technical analysis, they consider one option as the technical solution to the problem of urban flooding in the area, i.e., upgrading the current sewer system in the back alley to a separate sewer system and implementing SUDS on private property to combat flooding. Similarly, the water board also does not perceive a dilemma. Their actions and goals are mostly concerned with surface water issues and they expect the options at their disposal, i.e., installation of pumps and dams on inner city canals, and controlling the discharge into surface water as being sufficient to achieve them.

Action and goal conflicts

On comparing the cognitive maps across actors, we found no goal conflict, i.e., all actors want the same direction of change in shared goals (see supplementary material F in Mittal et al., 2024b). For instance, both monumental and non-monumental residents want "sustainable impact" to increase and "household costs" to decrease. With respect to action conflict, we see that the actions of the municipality, i.e., upgrading the public underground sewer system either in the back alley or laying a new system in the front street create a potential conflict with the monumental residents (see supplementary material G in Mittal et al., 2024b). Although both these solutions would lead to better public health, more liveability, and long-term viability of the measure for the residents, the former option would lead to an increase in "nuisance due to construction work" which is undesirable for them.

Table 3-3: List of most frequent variables across cognitive maps of all actors. Column 2 (relevance) equals the number of actors that mentioned the variable

Variables	**Relevance**
Flooding from overflowing manholes	5
Separated stormwater and sanitary wastewater flow	5
Aesthetics of the inner city	4
Long-term maintenance and viability of solution/measures	4
Nuisance due to construction work	4
Land subsidence	4
Facilitation of arrangements among private owners	4
Provide subsidies to households to implement SuDS on their private property	4
Storage and drainage capacity in existing "bulged" sewer system (partially full of water, hinders free gravity flow)	4
Heavy cluster storm showers	4
Heat stress	4
Groundwater (GW) level	4
Rearrange in-house piping to connect to sewer pipes in the front	4
Nuisance inside the house	4
Costs to treat wastewater at the WWTP	3
Moisture in houses	3
Liveability	3
Public health	3
Runoff to the sewers	3
Green and blue areas	3
Flood damage to electrical system, paint work and house construction	3
Stormwater infiltration in the ground	3
Heavy cluster storm showers	3
Fair distribution of investment and maintenance costs among residents	3
Changes to monument houses	3
Stormwater storage	3

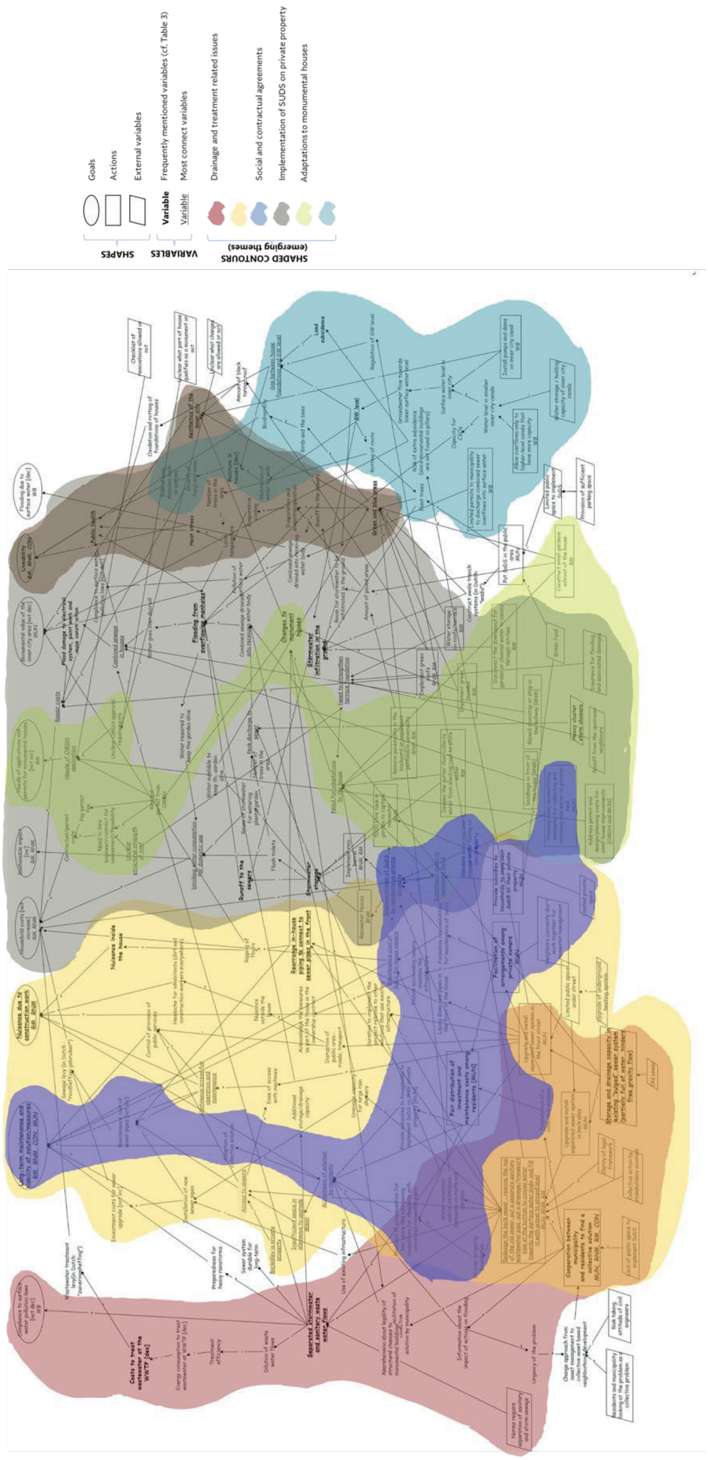


Figure 3-8: Aggregated system map based on the perceptions of the actors for the case study

Shared concepts or similarities

Table 3-3 shows the actors' shared variables with a frequency of 3 or more. A full frequency table is provided in Supplementary material H (Mittal et al., 2024b). As can be seen from Table 3, the variables "Flooding from overflowing manholes" and "Separated stormwater and sanitary wastewater flow" emerge as important which aligns with the focus of the interviews and the current trend in literature respectively (De Toffol et al., 2007; Skambraks et al., 2017). In addition, the results highlight the importance of the need for the provision of subsidies, fair distribution of investment costs, and facilitation of agreements between households to ensure that the solution which is implemented is viable and financially sustainable in the long run. Other relevant variables are the nuisance effects of construction work – both inside and outside the houses, liveability, heat stress, moisture in houses and health concerns signalling the need for considering these aspects while evaluating the solutions that are undertaken to solve the flooding problem in the study area.

3.4.2 | Combined systems map – selecting a problem scope

Figure 3-9 shows the CSM with various features marked on the map. The variables are arranged hierarchically similar to actor-level cognitive maps. We first analysed the CSM to identify important variables that should be considered while selecting a suitable scope for the serious game. Firstly, we looked at shared variables to identify emerging topics/themes that can be further used to select a suitable scope for the game.

Structure and emerging themes

The structure of Figure 3-9 shows a high number of tails/actions indicating the wide range of possible options for alleviating the issue of flooding. Similarly, the CSM has many heads/goals, indicating that there are many (possibly conflicting) goals at play. Furthermore, we identified six topical clusters that emerged around the most shared factors. They indicate sub-parts of the system that lead to issues and dilemmas around the focal problem of urban flooding, namely:

1. Drainage and treatment-related issues (marked in red): This cluster concerns the separation of stormwater and wastewater as a critical issue in the upgrade of the sewer system.
2. Interaction between surface water levels and groundwater levels (marked in blue): This cluster is focused on the actions of the water board to lower the groundwater levels.

3. Social and contractual arrangements required for implementing a collective solution (marked in purple): This cluster is about the arrangements necessary for the adoption and acceptance of a collective solution and to ensure its long-term maintenance, without which it would not be socially nor technically viable.
4. Upgrading the underground sewer infrastructure (marked in yellow): This cluster focuses on the dilemma of upgrading the sewer infrastructure in the back alley or the front street and the accompanying impact on nuisance and long-term maintenance of the measure.
5. Implementation of SUDS on private property (marked in grey): This cluster focuses on the pros and cons of implementing SUDS on private property. On the one hand, they improve aesthetics, heat stress and biodiversity. On the other hand, they lead to an increase in household costs and the hassle of applications and seeking permits for monumental houses.
6. Adaptations to monumental houses and associated challenges (marked in green): This cluster deals with the issue of adapting monumental houses to implement SUDS.

Central variables in the CSM

Lastly, we look at the most central (connected) system variables, i.e., the nodes with a considerable number of arrows directed towards or away from them (underlined variables in Figure 3-9). These variables indicate bottlenecks in the system or variables that are critical because they are connected to many other variables. For instance, rearranging in-house piping (see cluster 3 marked in yellow in Figure 3-9) is a critical variable in the decision to upgrade the sewer infrastructure as it impacts many other upstream goals such as maintenance costs of sewer upgrade, household budgets, and nuisance due to construction work.

Starting from a broad problem statement/need for the serious game, the systems analysis helped surface more specific problems, issues and critical variables. The CSM can be further used as a foundation for discussions with the client or problem owner. At this stage, depending on the selected scope, it could also be worth discussing whether other methods such as a simulation model or a participatory workshop might support the decision-making process better compared to a serious game. Assuming a game is selected as the method to address the problem, the results of the individual cognitive maps and CSM can be further translated into game elements for Phase 3 of the game design.

3.4.3 | Implications for game design

After developing the CSM, the selection of the boundary and the scope of the problem to be addressed in the serious game should be made with the problem owner. Alternatively, a preliminary scope can be selected by the game designer to develop an initial game prototype and iterate on it through feedback from gameplay validation sessions. In this section, we illustrate Phase 3 of the game design process by providing an example of a scope that highlights the multi-actor perspective focused on the issue of flooding from overflowing manholes (yellow and grey contours), leaving out issues that are of relevance only to a single actor, e.g. wastewater treatment, and land subsidence (blue and red contours respectively).

Starting with the overall game objectives, the shared goals from the combined map (see supplementary material F in Mittal et al., 2024b) - "long-term maintenance and viability of the measures" and "liveability", along with reducing flooding provide a starting point. Furthermore, we see that the municipality and residents have different perspectives on solutions to implement and they are dependent on each other for resources. We also observe that the current solution proposed by the engineering consulting company is too specific, and limits the combination of individual solutions (sewer in front or back alley and implementation of SUDS) that create a dilemma for the municipality and residents. To engage different actors in the case study, a potential game resulting from this analysis can focus on providing players a greater degree of freedom in exploring and combining individual sewer and SUDS options and understanding the consequences and dependencies related to each solution. Hence, the overall objective of the game could be to explore different solutions, assess their performance, and come up with a collective solution.

Key player roles to include in the game would be the actors that lie within the chosen scope in the CSM (yellow and grey contours), i.e., the municipality, monumental households and non-monumental households. The actions of other actors – the consulting company and the water board do not directly impact the chosen scope and they can be taken as supporting/non-playable roles that set the challenge for the game. For instance, in the initial challenge description, players can be asked to come up with a separated sewer system design as recommended by the water board norms whereas the consultants can provide underlying technical information to assess the performance of individual solutions.

Key player actions to include will be the "upgrading of sewers in the front street", "upgrading sewers in the back alley", and the range of SUDS that can be implemented by non-monumental houses and monumental houses on their private property. Given the restrictions on monumental houses, they will have access to a lower range of options compared to non-monumental houses since solutions such as green roofs, green facades, construction of small gardens, etc. would lead to structural or aesthetic changes to the house.

Individual goals from the actor-level cognitive maps can be translated into player objectives. Here, contentious goals that cause dilemmas for the players should be included to challenge the players to make trade-offs and explore conflicting goals. These goals can be further operationalized to measure the performance of solutions and the attainment of individual and collective goals. For instance, each sewer option to be implemented can have corresponding investment costs, maintenance costs, costs of re-piping connections to the sewer, and a nuisance and ease of maintenance score on a scale of 1-10. Similarly, the implementation of blue-green solutions can be measured on additional storage volume created (in m3), investment costs, maintenance costs and added blue-green area (in m2) which could be used as a proxy for livability and biodiversity.

Players can be provided access to different resources. While the municipality controls public space, households are in charge of private space. Households pay levies and taxes to the municipality which are further used to change any public infrastructure. Similarly, the municipality has funds and can provide subsidies to the households for the implementation of SUDS.

Lastly, rounds could be setup as a group planning exercise where residents and municipality individually come up with their own combination of sewer options and SUDS for a design rainfall on how to deal with the issue of flooding in the neighbourhood. In the subsequent round, they can come together as one group to discuss and compare their solution on the performance indicators and then negotiate for a collective solution. The external factors “heavy cluster storm showers” or budgets available from water board or the national government such as the “green fund” can be used as additional events to increase the challenge for the players as the rounds progress. In the debriefing, players can be asked to reflect on the solutions they came up with during the game and the resulting legal and financial challenges of implementing them in the real-world.

3.5 | DISCUSSION

3.5.1 | On the proposed methodology

In this chapter, we present a methodology for conducting systems analysis in the serious game design phases and apply it to a Dutch case study on urban flooding. Current co-design processes for urban flooding issues usually start with researchers conducting workshops or meetings with actor groups (Chapa et al., 2023; Dobre et al., 2021) or creating digital participation tools to gather insights from citizens and representatives of private and public sectors to understand the initial problem (Arlati et al., 2021). We believe our proposed methodology contributes to structuring and analysing the data collected through these activities and surfacing key dilemmas to be explored in successive activities. Similarly, current decision-support systems for stormwater management are primarily designed from the perspective of one actor (Sun et al., 2024) and can benefit from the combination of actor analysis and cognitive mapping to incorporate the perspectives of multiple actors. Although applied to a case study on urban flooding, the methodology is generic and can be applied to any complex problem to get a broader perspective, understand actor perspectives and identify key elements of the real-world system for subsequent game design.

The methodology contributes to existing game design frameworks (e.g. Bjork & Holopainen, 2005; Duke, 1974; Duke & Geurts, 2004; Klabbers, 2006; Peters & Westelaken, 2014; Freese & Lukosch, 2023) by zooming into the Phase 2 of game design and demonstrating how actor analysis and cognitive mapping can be used for system analysis. While actor analysis helped identify, categorize and prioritize different actors, cognitive mapping helped to capture their perceptions and surface the dilemmas they faced. Game developers seeking deeper exploration or conflict identification among actors can deploy other methods for comparing cognitive maps of actors and identifying critical factors in the overall combined map. These may include looking at map density, shape, number of feedback loops, number of variables, number of links, link to variable ratio and more (Eden, 2004). Tools like Decision Explorer (https://banxia.com/) or Cognizer (Clarkson & Hodgkinson, 2005) can be used in implementing these methods. In future studies with large samples, a mixed methods research design could enrich the analysis to derive significant patterns from the cognitive maps as inputs for game design and evaluation.

Furthermore, there are a plethora of other actor analysis methods that can be used for instance social network analysis or conflict analysis, see (Hermans & Thissen,

2009) for an overview of these methods. Similarly, causal loop diagramming is an alternative, well-known approach for visualizing mental models (Sterman, 2000). The method builds on the foundations of systems dynamics (Meadows et al., 1972) and focuses on mapping the dynamic and feedback aspects of systems through reinforcing and balancing feedback loops (Haraldsson, 2004). These models are typically built in a group setting where actors are engaged in a structured process to collectively construct the model (Rouwette et al., 2002; Vennix & Forrester, 1999; K. Zhou et al., 2022), yet examples exist where these have been constructed from interviews (Guariguata et al., 2020) and text data (Sundar Navamany et al., 2022).

Our proposed methodology is further limited in that it only covers the "reality" aspect of game design. However, we acknowledge that aspects of Meaning and Play, that follow after developing a good understanding of the real-world system (Harteveld, 2011; Harteveld et al., 2010) might necessitate further considerations to ensure the game's playability and achievement of its (serious) purpose. Filling the game design matrix using the CSM may not lead to a complete game design. Additional simplifications and iterations might be required to fine-tune, simplify, or readjust the representation of reality in the game, with the overarching goal of enhancing playability. Furthermore, given the qualitative nature of the methods used, subsequent game design steps might involve quantifying causal impacts, potentially requiring the development of a detailed simulation model. The CSM can still serve as an initial conceptual model for quantitative model building.

3.5.2 | Application of the methodology

The application of the methodology to the case study shows that Monuments department and REA emerge as additional important actors from the actor analysis process. However, we could not access a representative from the organization for interviews and hence, their detailed perspective could not be taken into account. Since the Monuments department is not included in the analysis, we assumed that the current regulations around monumental houses are a given and changing them is outside the scope. However, if the scope of the game is selected such that the rules surrounding adaptations to monumental houses were a critical issue, then the detailed perspective of Monuments department should be taken into account in another iteration of systems analysis, along with considering them a player in the game to be developed. Similarly, the scope of the analysis could also be expanded by incorporating the perspective of actors such as financing institutions, and infrastructure companies if the problem scope is to be focused on the technical implementation of solutions.

Furthermore, this research was qualitative in nature, and focused on capturing the perspectives of diverse actor groups through cognitive maps. The intention was not to capture the breath of viewpoints and figure out the differences in perspectives within each actor group which would require more interviews with members of the municipality. However, we do acknowledge that potential sampling bias exists as the participants who were interviewed were already aware of the urgency of the issue of urban flooding and were motivated to act towards addressing it. For instance, the residents who were interviewed are already part of a group that meets regularly to discuss water issues in the neighbourhood. This implies that the information collected through the interviews was sufficient and the corresponding cognitive maps were detailed. We expect that this may not be the case with other participants who lack the urgency and awareness of the issue, leading to less detailed cognitive maps.

The aim of this research was to present a methodology for a game designer or decision analysts who use game to support decision processes to structure the real-world problem system, to better represent the key issues and problems in the serious game and open up a space for player participation that has a higher chance of success given the game's goal. In this research, interviews were used to collect data and the researchers designed the CSM as a preparatory step to design the game. While building cognitive maps, the authors supplemented gaps in logic or lack of explanations based on their own perceptions and subject-matter expertise. We did not plan to involve actors in developing the CSMs nor validate the developed CSMs with them. This could be done as part of the research design if the goal of the design process is to attain problem understanding through the cognitive mapping process. In such as case, the validity of the cognitive maps can be improved by co-developing them with the actors, either in a group (Damart, 2010; Özesmi & Özesmi, 2004) or individual setting (Hermans, 2004, 2008). Constructing maps in such a setting would require additional effort and resources in explaining the underlying concepts of the cognitive mapping method to the participants to co-create the map together. However, if the serious game is the means to induce the intended learning effects, then prior validation of the maps would make it difficult to tell apart the learning effects induced by the design of the game and game play intervention or the cognitive mapping exercise.

As with any qualitative research, there is a level of subjectivity as the research is dependent on the researchers conducting the analysis and is shaped by their worldviews (Noble & Smith, 2015). We tried to minimize the researcher bias by conducting an internal validation of cognitive maps in the research team (Roulston & Shelton, 2015). However, we acknowledge that the resulting analysis is based on the researcher's interpretation, and there may be a gap between the collected data and its interpretation.

3.5.3 | Implications for future use

The methodology we propose in this chapter can help game designers and decision analysts incorporate the perspectives of as many actors as they like by building and collating their cognitive maps. Following the methodology can add more realism to the final game as well in the sense that actor-level information their interactions, dependencies, and conflicts would be well represented in the game. However, it is important to note that the method is one way of building a model of reality based on how the analyst perceives it and as with any model, most of them are wrong and some are useful. It would still be critical to implement Phase 4 of the game design process to try the game prototype with a test audience to check whether the dynamics of the reality as perceived by the game designer or decision analyst aligns well with the real-world or not.

Furthermore, implementing the proposed methodology of systems analysis will require planning additional time for the game development process. Depending on the composition of the game design team/researcher, team members might need to familiarize themselves with the problem structuring methods. Similarly, conducting interviews and gathering information for cognitive mapping and discussing the interim results of the process with the client will require additional time.

We expect that a game developed through a structured process as demonstrated in this study will exhibit higher validity for the game users and contribute to solving the 'right' problem compared to those developed using more intuitive methods. Future work should focus on comparing different design processes - with and without a structured systems analysis and validating the end product with subject-matter experts to gauge the benefits of conducting such a structured analysis.

3.6 | CONCLUSIONS

Systems analysis is a critical phase in game design for supporting decision-making for complex problems. However, current serious game design processes rely too much on intuition and experience and lack rigorous and structured approaches on how to analyse the real-world system and translate it into a conceptual map for game design. In this chapter, we propose a methodology to improve systems analysis by combining two problem structuring methods: actor analysis and cognitive mapping. We use actor analysis to identify critical actors to include and use cognitive mapping to capture their perceptions about the complex system and problem(s). Analysis of the resulting cognitive maps helps surface specific issues and problems that could be addressed in the serious game. It further serves as a sound foundation for selecting the scope of the game and for mapping the real-world system to game design elements, as exemplified in dealing with the challenge of urban flooding in a Dutch neighbourhood.

Our main findings are:

1. The proposed methodology provides a structured, transparent and rigorous approach for conducting Phase 2: Systems Analysis as part of the game design process;
2. Starting from an initial problem description, game designers or decision analysts aiming to use games for decision support can analyse the multi-actor dynamics underlying the complex problem by leveraging actor analysis and cognitive mapping;
3. Actor analysis helps identify relevant actors and incorporate their perspectives into the systems analysis – their actions, objectives, perceived uncertainties and the causality among these variables.
4. Individual cognitive maps of actors can help surface actor-level dilemmas and a combined system-level cognitive map can help identify similarities among actor perceptions and emerging issues and conflicts.
5. Overall, the proposed methodology can make choices regarding the scope of the game transparent and traceable and facilitate a translation of real-world systems by mapping elements of the combined cognitive map into game design elements such as roles, actions, events, performance indicators, and rounds.
6. The resulting cognitive maps can be used as a means for consultation and discussion between game designers, clients and other actors about alternative game designs

The research is limited in its endeavour for validity. We propose a methodology to structure the systems analysis process but do not test whether this leads to a “better” serious game. Since the scope of this chapter is focused only on initial problem analysis for game design, potential sampling and research bias present in the study were not tested and validated with real-world actors. Similarly, especially if collaborating with several actors, joint deliberation and negotiation of the problem to be addressed and the features of the game may follow in the subsequent Phase 4 – Game construction, validation and testing of the game design process. Furthermore, given the qualitative nature of the study, interpretative subjectivity in the research process remains

We recommend serious game designers or decision analysts to apply and systematically evaluate the methodology in experiments and/or real-world case studies. This shall not only help to gauge the benefits against the costs of such analysis, next to identification of specific challenges, learnings, and modifications necessary to further improve the approach and derive generalizable recommendations for its use. We further encourage game developers to report the outputs of their systems analysis in their publications/reports. This will enable a better understanding of the choices behind the scope selection and the underlying relations between actors, actions, objectives and uncertainties covered in the game.

4

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

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ABSTRACT

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

4.1 | INTRODUCTION

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

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

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

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

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

4.2 | EDUCATING WITH A SERIOUS GAME

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

4.2.1 | Serious games for education and raising awareness about SUDS

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

Serious games are widely employed to educate and raise awareness about urban water management issues (see D'Artista and Hellweger 2007; Hirsch 2010; Appel et al. 2019; Rebolledo-Mendez et al. 2009; Novak et al. 2018; Pereira, Prada, and Paiva 2014 for examples). However, when it comes to SuDS, mostly non-gamified, interactive (web) applications are available. For example, the Climate Resilient City Tool (CRC) can be used for urban planning and climate adaptation where SuDS are placed in a digital map of a specific area and their impact on criteria such as additional storage capacity, heat reduction, costs, etc. are displayed (Deltares n.d.; Van de Ven et al. 2016; Voskamp and Van de Ven 2015). Similarly, the web-based interactive tool

ClimateScan conveys knowledge about various ‘blue-green’ projects implemented around the world (Tipping et al. 2015). We could not find any serious game to educate the public about household SuDS.

4.2.2 | Knowledge gaps to be addressed in household SUDS adoption

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

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

4.2.3 | Designing the serious game for behaviour change through education

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

For the purpose of the serious game presented in this chapter, the pre-decision stage of the SSBC is the most relevant. During the pre-decision stage, a goal intention is formed as a result of various cognitive and affective changes. Goal intention serves as a pre-requisite for behavioural intention, where the individual forms a stance on a subject motivating and supporting a certain behaviour, expressed in statements such as 'I intend to reach this goal' or 'I intend to support X' (Bamberg 2013). It results from how one feels about a subject and one's personal norm. A personal norm refers to personally important moral standards that one desires to act in line with (Onwezen, Antonides, and Bartels 2013). Within the model, personal norms are influenced by perceived social norms, understanding the consequences of actions, feelings of responsibility, and negative emotions associated with the consequences of (not) taking an action. In other words, according to the SSBC, a person's moral standards are shaped when the consequences of behaviours (perceived as good or bad) are understood, and the person accepts their personal responsibility to do the right thing and behave in a way to avert feelings of guilt and shame for causing harm (De Groot, Bondy, and Schuitema 2021).

Section 4.2.2 identified SuDS-related knowledge gaps regarding household SuDS, indicating low awareness of consequences and low ascription of personal responsibility, as well as a lack of social norms and personal norms for adopting SuDS. Without awareness of the issues and consequences of various urban drainage measures, an individual is unlikely to form goal intentions for change.

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

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

4.3 | METHODOLOGY

The methodology of this study features several stages described in this section that follows the structure shown in Supplementary Material A (Nguyen et al., 2024b).

4.3.1 | Serious game design

The serious game intends to represent a version of reality in the form of a simulation game. The development of a simulation game typically takes place in 5 phases (see Figure 4-1, Peters and Westelaken 2014; Mittal, Scholten, and Kapelan 2022). This design process is iterative and may require going back and forth between steps and phases to address all aspects of each phase.

Phase 1: game design specifications

Phase 1 initiated with the formation of the game design specification (GDS), which was informed by the outcomes of Section 4.2 to construct clear learning outcomes. The GDS was approached with checklist-style questions for which the responses provided direction for the game design process while acting as criteria for validating the final game. The questions proposed in the GDS were adapted from the suggested specification checklist questions of Peters and Westelaken (2014) and covered the following themes: *background problem*, *objectives of the game*, *general considerations*, *elements of the game* and the *use of the game*. The detailed GDS is presented in Supplementary Material B (Nguyen et al., 2024b).

Phase 2: system analysis

In Phase 2, a desk study was conducted to analyse the real-world system. Existing information within the context of the Netherlands was examined and conceptual maps were created to identify important actors and factors related to the adoption of households SuDS. This was followed by a critical selection of the most important system elements to convey through the game, considering the GDS, shown in Supplementary Material C (Nguyen et al., 2024b). This stage was frequently re-iterated throughout the game design process.

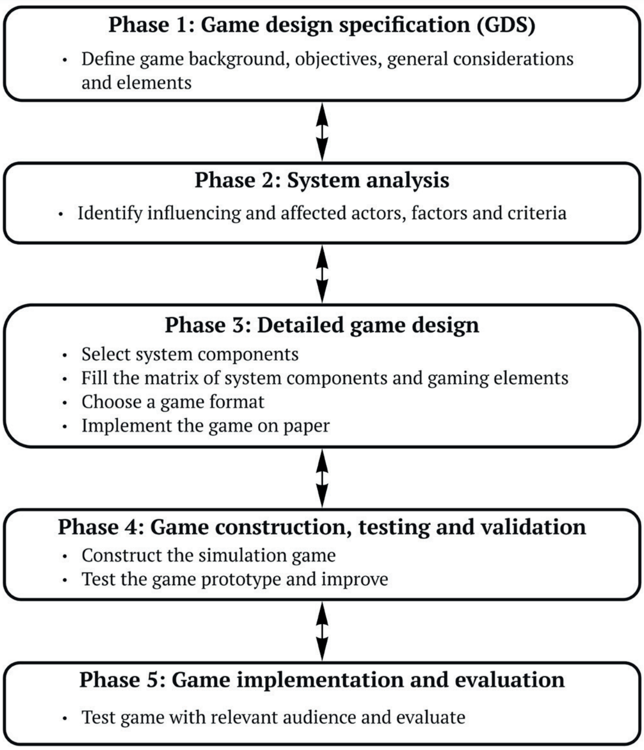


Figure 4-1: Phases of designing a simulation game (adapted from Mittal, Scholten and Kapelan 2022, Peters and Westelaken 2014).

Phase 3: detailed game design

Next, the relevant system components were mapped on a matrix against typical gaming elements that facilitate the mechanisms and dynamics of the game such as roles, rules, actions, chance, limited actions, resource scarcity, conflict etc (Peters and Westelaken 2014; Pendleton 2020). The matrix helped generate ideas and demonstrate how aspects of the system could be translated into game elements (see supplementary material D in Nguyen et al., 2024b). Entertainment games such as Pandemic: Rising Tide (Z-Man Games 2017), Bärenpark (Lookout Games 2023), and Scoville (TMG, n.d.) were also examined for inspiration on how to translate real-life processes into board game elements. For example, Pandemic: Rising Tide's (Z-Man Games 2017) representation of climate change as increasing sea levels inspired the inclusion of increasing volumes of rain showers and the use of physical blue cubes to represent rainfall in SuDSbury.

The final stage of Phase 3 was focused on creating '*the game on paper*'. This involved creating diagrams and visual maps to translate gaming elements into physical components for the board game. This stage was highly experimental and required several adjustments and re-iterations of all steps within Phases 2 and 3 of the game design. The basic criteria considered while doing the iterations were to balance game realism, meaning and play aspects, i.e. the game should represent the real-world while also being playable and fun as a board game and conveying the appropriate meaning as stated in the learning objectives (Harteveld 2011). Examples such as Levee Patroller (Harteveld et al. 2010) and GBGame (Juan and Chao 2015) provided insights into achieving this balance. These included balancing gameplay challenge versus achievability while maintaining realism, largely pertaining to scoring and cost scales, explained further in section 4.4.3. The gameplay challenge level should also convey the urgency to act in response to climate change which is discussed in section 4.4.4.

Phase 4: game construction, testing and validation

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

Phase 5: game implementation and evaluation

Finally, in Phase 5, the final SuDSbury game prototype was evaluated with the target audience, as described in section 4.3.2.

4.3.2 | Game evaluation

The serious game was evaluated using a 'quasi-experimental' design, where participants completed a pre-game and post-game survey (see Supplementary Material E in Nguyen et al., 2024b) to measure changes in their responses before and after playing the game (Hauge et al. 2015). The target audience for the game was adults (18 years of age or older) living in an urban area. The trial was conducted in the city of Delft in the Netherlands. Recruitment was done through leaflets, posters (see Supplementary Material F in Nguyen et al., 2024b), and personal contacts, with respondents encouraged to invite others. During recruitment, participants were made aware that they would be testing a new educational serious game. Participation of players was voluntary and no financial incentives were provided. A total of 14 participants could be recruited, which is a typical sample size for initial results and feedback in serious game interventions (e.g. Gomes et al. 2018 used 9 participants and; Khoury et al. 2018 used 22 participants).

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

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

Knowledge and comprehension

The serious game aims to educate the public on knowledge gaps regarding private household SuDS and thereby influence personal norms, as described in section 4.2.1. To test the game's impact on knowledge acquisition, a knowledge test was developed that consisted of multiple choice questions (MCQ) and open questions

(Hauge et al. 2015; Li et al. 2017; Mayer et al. 2014). Following Mayer et al. (2014)'s recommendation, participants were also asked to self-report their understanding/awareness levels related to the learning objectives.

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

Personal norm stance

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

Game feedback

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

Data analysis

The data analysis of the survey varied based on question type. Each MCQ was designed to feature correct and incorrect answers (correct answers are highlighted in Supplementary Material E in Nguyen et al., 2024b). For each question, the 14 individual responses were grouped to find the percentage of participants who responded to each question correctly or incorrectly.

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

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

4.4 | THE SUDSBURY GAME

4.4.1 | Game setting

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

Players can assume one of six unique roles which provide them access to build on their associated housing blocks on the board (see supplementary material G in Nguyen et al., 2024b for all role cards):

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

The game was designed to set the scene, game mechanisms and goals that deliver the two learning objectives as outlined in section 4.2.3. The introduction to the game sets the storyline that the SuDSbury neighbourhood is facing issues with pluvial flooding and has failed to secure funding to upgrade its sewers. The effect of climate change and urbanisation escalates in the game timeline in the form of increased risk of intense weather events, and loss of neighbourhood parks due to increased housing, as described in sections 4.4.2 and 4.4.4. Therefore it is up to the residents (players) to reduce pluvial flooding while also improving the town’s liveability. These two objectives are represented as scoring criteria for the game where flood reduction represents the amount of overland water retention in the area, and liveability represents all environmental and social aspects that contribute towards quality of living.

Figure 4-2: Game board and associated paraphernalia of SuDSbury as arranged in the starting set-up of the game.

4.4.2 | Game round

The gameplay is facilitated by a facilitator to introduce the game objectives and rules and guide the players through the game. The facilitator starts the gameplay by delivering a short presentation on the game which sets the scene for the game story and covers topics such as roles, game objective, scoring, round actions, rules, and winning and losing conditions (see supplementary material H in Nguyen et al., 2024b).

After the presentation, players are provided with the gameplay material including role card, action cards, and item cards, which they can access throughout the game. Players begin the gameplay which consists of nine rounds that represent the years 2022 to 2030. Within every round, each player has one action per turn (see the left card of Figure 4-3). An action can be to implement/purchase an item for their land (if landlord approval and concerns checks allow), or to repair up to two failed items, remove an item, or pass. These actions allow the players to contribute to SuDSbury's liveability score and flood protection level. At the end of a round, a weather event takes place where a drought or flood could occur with associated consequences such as the impact on liveability score and SuDS damage. If players manage to survive the impact of the flooding/drought, they can move on to receive their annual income, pay maintenance, and proceed to the next round.

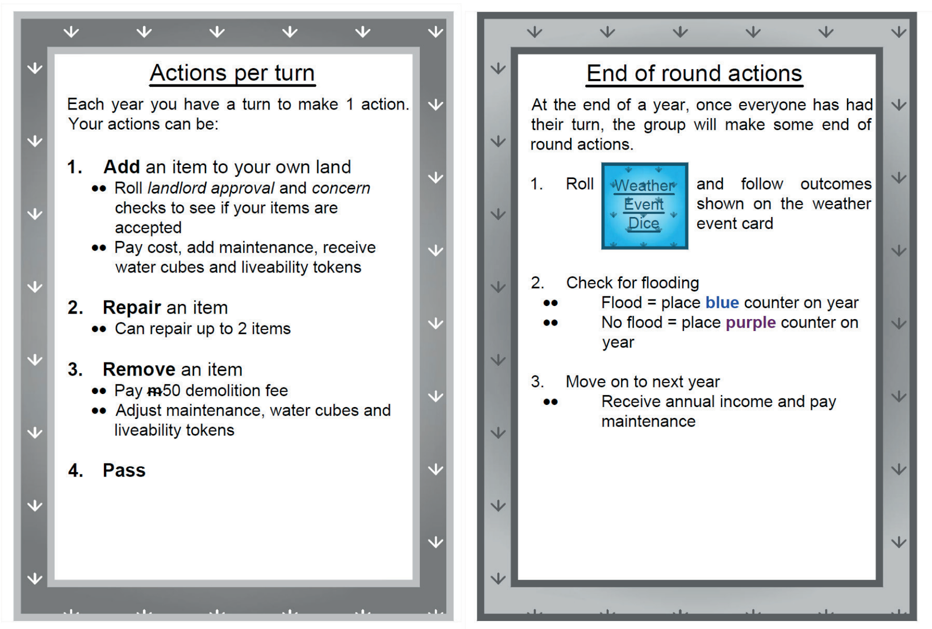


Figure 4-3: Cards explaining game actions and round mechanisms.

4.4.3 | In-game items

Players can influence liveability and flood reduction scores by implementing items on the game board. There are eight items available, with one description card each (example shown in Figure 4-4, see supplementary material G in Nguyen et al., 2024b for all other item cards). Six of these items are SuDS, and two are home improvements. The item cards provide a short description of the item along with their pros and cons, liveability scores, water storage capacity, fixed costs, and annual maintenance costs. More information on how the costs and liveability scores are calculated are provided in supplementary material I in Nguyen et al. (2024b).

Figure 4-4: Example of an item card.

Access to these items depends on player roles. For instance, a house owner with no garden can only purchase and implement items that can be put on the roof or the paved area of the house, e.g. a green roof, solar panel, or a rain barrel (see supplementary material G in Nguyen et al., 2024b for example). Implementing an item requires players to fulfil certain conditions. All players must roll a ‘concern’ dice to determine the chance of a neighbour or a member of the housing association raising concern about the proposed item. There is a 1/3 chance of receiving a ‘concern’ and if a concern arises, the player can answer a *‘justify card’* to convince the neighbour to accept the item. Justify cards test factual trivia on pluvial flooding and drainage mechanisms to familiarise the audience with definitions and issues relating to SuDS items (see supplementary material G in Nguyen et al., 2024b for examples). If answered incorrectly, implementing the SuDS is blocked. Players who rent an apartment or a house need to roll an additional dice to check if the landlord accepts their proposed items. The landlord dice has an equal chance (1/ 3) of blocking, accepting, or accepting the item with a financial contribution.

4.4.4 | Weather events and flooding

The weather events that occur at the end of every round (year) follow the logic checks shown in Figure 4-5. Depending on the *weather dice*, rain or drought may occur. The outcomes of each weather event are detailed on a *Weather event card* (see supplementary material F in Nguyen et al., 2024b). The impact of droughts is decreased *liveability*, damage to SuDS vulnerable to droughts and financial bonuses for those with solar panels. The rain events are followed by a (numerical) *rain dice* roll to determine the number of rain cubes that SuDSbury's sewers and land (represented on the *flood reduction* scale) have to handle. To represent climate change, as time progresses in the game, the chance of getting intense weather events increases as the dice faces include more severe drought and increased rain multipliers.

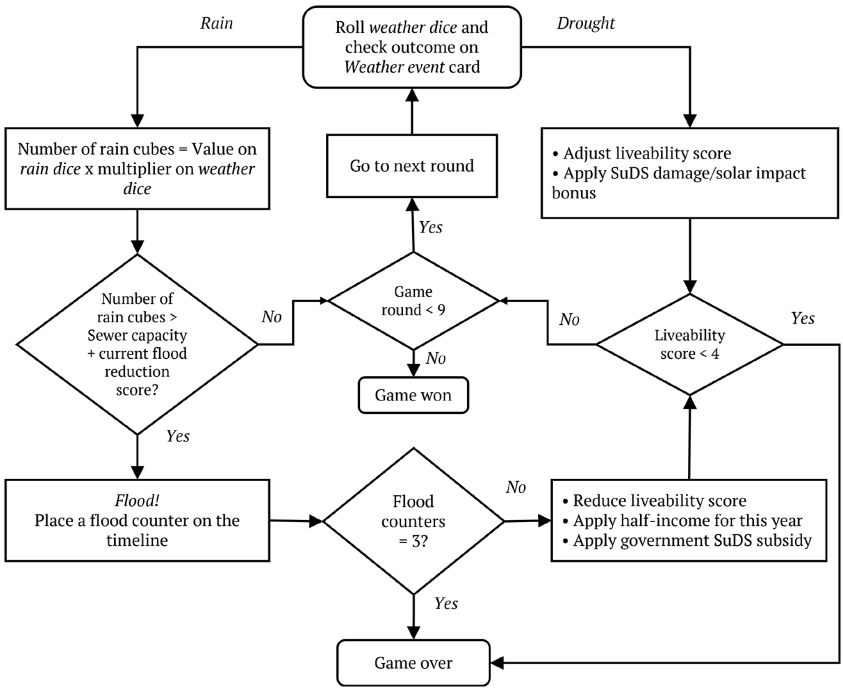


Figure 4-5: Flowchart of flooding, winning and losing in the SuDSbury game.

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

4.4.5 | Winning and losing conditions

In the game, the players' objectives are to reach *good* liveability scores and increase flood reduction scores such that the town can survive weather events. All players work together towards this aim by familiarizing themselves with criteria and scores of implementable items as described in section 4.4.3. All players are affected by the losses and gains, e.g. a flood reduces liveability score which translates to low income for all (and vice versa). As shown in Figure 4-5, to win the game, players must complete nine rounds, reaching the year 2030, while maintaining a liveability score greater than four and having less than three floods. If the game is won, it is a collective victory for all players, but the player who contributed the most to the overall scores is recognized as the winner. However, the game is lost if the town experiences three floods or if the liveability score drops to the minimum value of four. For further details on the game paraphernalia, see Supplementary Material F in Nguyen et al. (2024b).

4.5 | SUDSBURY EVALUATION RESULTS

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

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

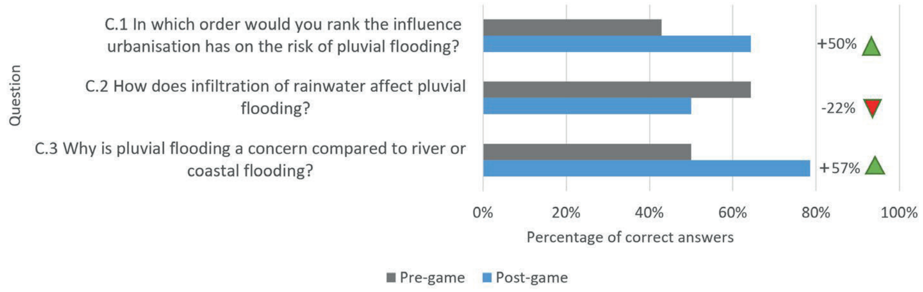


Figure 4-6: Pre- and post-game percentage of correct answers to questions C.1, C.2 and C.3 (the percentages on the right of the chart indicate the % change in the correct responses)

4.5.1 | Knowledge and comprehension

The results show an increase in group average knowledge and comprehension gained after the game (see Supplementary Material J in Nguyen et al., 2024b). The largest improvement was observed in the knowledge acquisition section. The knowledge acquisition section of the survey contained three open questions. Not only were more correct answers collected post-game, but of those correct responses, the post-game answers were generally richer and considered more aspects than mentioned pre-game, although they did not capture full descriptive sentences. Every question or statement indicated a group average increase except one comprehension question (see C.2 How does infiltration of rainwater affect pluvial flooding? in Figure 4-6) that resulted in a decrease (22%) in correct answers after the game.

The results of the self-reported learning section (Figure 4-7) show that the pre-game awareness level of topics (statements S1-S5) related to learning the urgency to act in the context of urbanisation and climate change (LO1.1) are significantly higher than initial awareness levels on topics relating to household SuDS (LO1.2; inferred from statements S6-S9). Subsequently, the improvement in awareness level of LO1.2 topics after the game is significantly higher than for LO1.1 topics.

4.5.2 | Personal norm attitudes to SUDS

The results of participants' personal norm stances on SuDS adoption are shown in Figure 4-8. All statements that pertain to acceptance of household SuDS observe an increase in acceptance, with a 25% or more increase in the average response post-game compared to the pre-game responses.

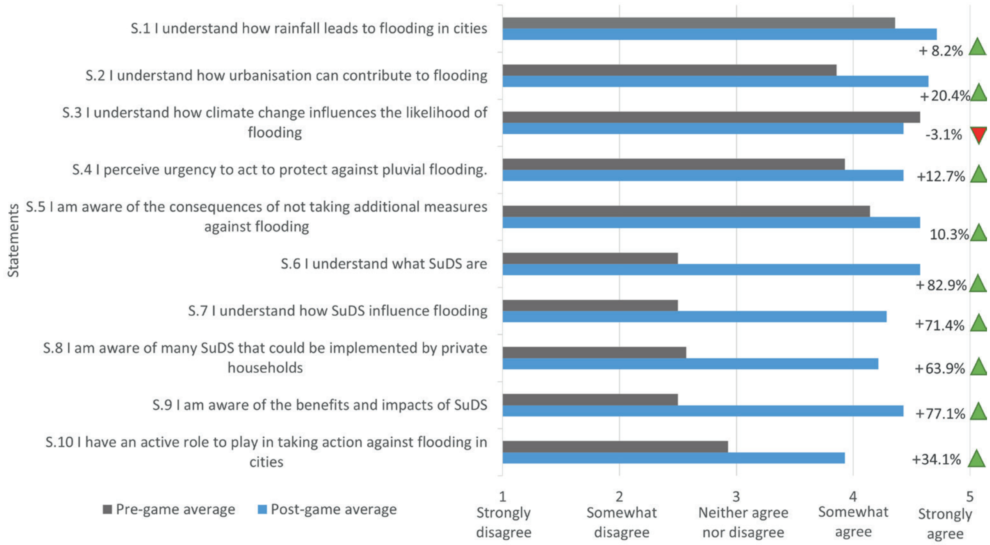


Figure 4-7: Pre- and post-game average score of 14 participants on self-reported knowledge and comprehension levels of household SuDS (the percentages on the right of the chart indicate % change in the average response)

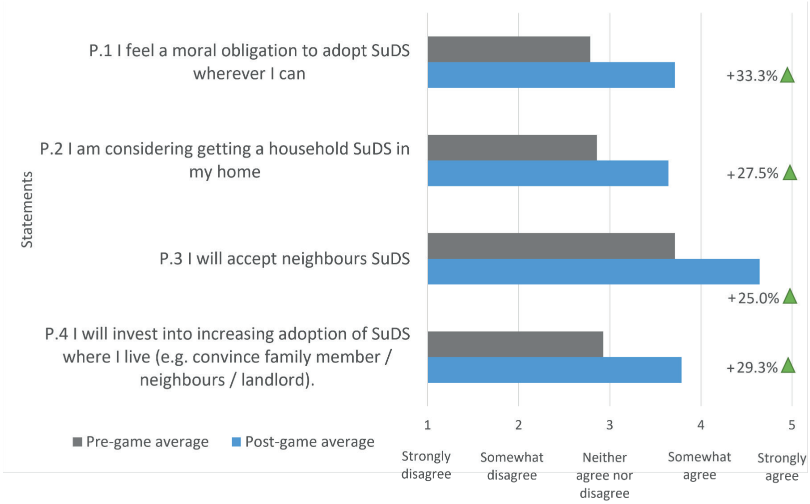


Figure 4-8: Pre and post-game average score of 14 participants on personal norm attitudes towards household SuDS (the percentages on the right of the chart indicate % change in the average response)

4

4.5.3 | Gameplay experience

Following the game, participants provided feedback on the gameplay experience on a scale of agreement shown in Figure 4-9. Overall, the groups strongly agreed that the game was fun, engaging, and the rules were clear. The group somewhat agreed that the game was easy to follow, and they learnt a lot in the game. The group somewhat agreed that the game was realistic and neither agreed nor disagreed that the game was easy to win.

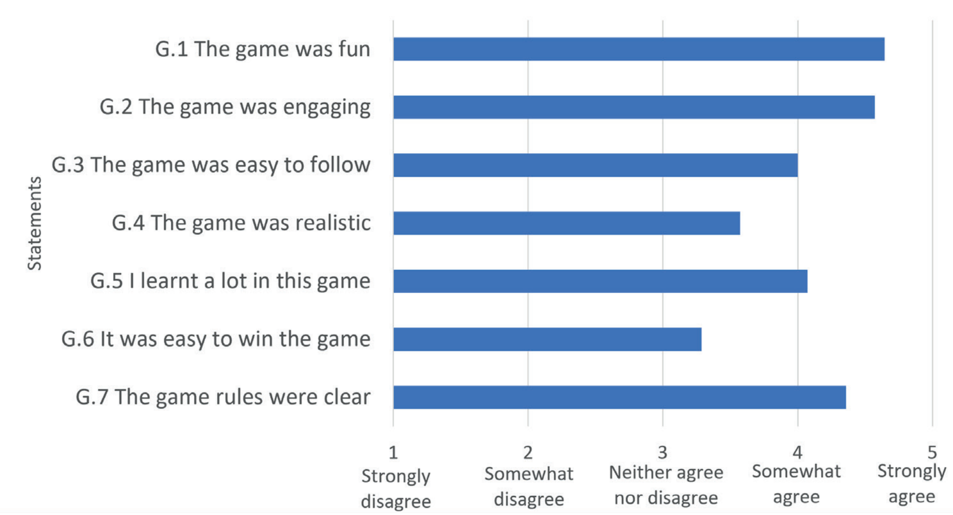


Figure 4-9: Post-game average rating of 14 participants for gameplay experience

Participants further responded to open questions (full responses are presented in Supplementary Material J in Nguyen et al., 2024b). 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, participants suggested improvements such as: '*Adjust the sewer capacity*', '*Make it a trade-off between water absorption and money*' and '*Try to be more realistic. Not all people are available to implement water SUDS*'. On describing their learnings from the game, participants responded with statements such as: '*I have learned about SuDS*' and '*I learned a lot*'. Three participants mentioned that they were surprised to learn that specific household SuDS, or SuDS in general, can impact flooding. Three participants mentioned they were surprised to learn that 'we' (as the general public) or individual households could impact pluvial flood risk. On the topic of the challenge or difficulty level of the game, one participant suggested '*Make it a bit harder*'. On the clarity of game rules and ability to follow the game, responses ranged from statements such as: *'Game rules could be more specified'* to *'It was very clear for me'*.

4.6 | DISCUSSION, LIMITATIONS AND RECOMMENDATIONS

4.6.1 | Game performance

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

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

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

The game was less successful in impacting participant comprehension level than knowledge acquisition. Comprehension is a more evolved thinking process, therefore requires understanding and interpretation of concepts. Comprehension question C.2:

How does infiltration of rainwater affect pluvial flooding? scored particularly low after the game. Upon reflection, the game inaccurately represented infiltration processes by equating it to retention within the game mechanics. This highlights the need for accurate game realism and showcases the drawback of oversimplification in serious games. To improve realism, distinction in the game mechanics should be made for SuDS that infiltrate, retain, attenuate, convey, filter and collect as a resource. Introducing a 3D version of the board game or an accompanying simulation system can provide players with a better understanding of how stormwater travels away from the visible urban subsurface which is difficult to imagine in a 2D game.

The study supports the causal dependencies posited by the SSBC model (presented in section 4.2.3), showing that the educational game intervention can influence personal norm stance towards household SuDS adoption, albeit through mediation and moderation by other variables (Steg and De Groot 2010). The serious game influenced the formation of goal intentions and demonstrated potential for deliberative behaviour change. Further work would be to assess the impact of the game on long-term awareness levels and personal norms. Additionally, data on the moderating and mediating variables can be collected to ascertain the contribution of awareness-raising as compared to the effects of other variables on the formation of personal norms.

4.6.2 | Game design

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

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

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

4.6.3 | Testing procedure

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

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

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

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

4.6.4 | Game viability and accessibility

While SuDSbury can be played by 4 to 6 players, it can be reproduced and translated to make it available to a wider audience. Municipalities, community organizers and educators who interact with urban residents are encouraged to use the game in their engagement activities. For example, the game can be used during planning or engagement sessions related to urban water infrastructure projects at the neighbourhood level. By providing a safe space to better understand the urban drainage concepts and improve knowledge about households and other SuDS, the game can effectively engage urban residents and help obtain their support/buy-in for the proposed scheme(s) along these lines.

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

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

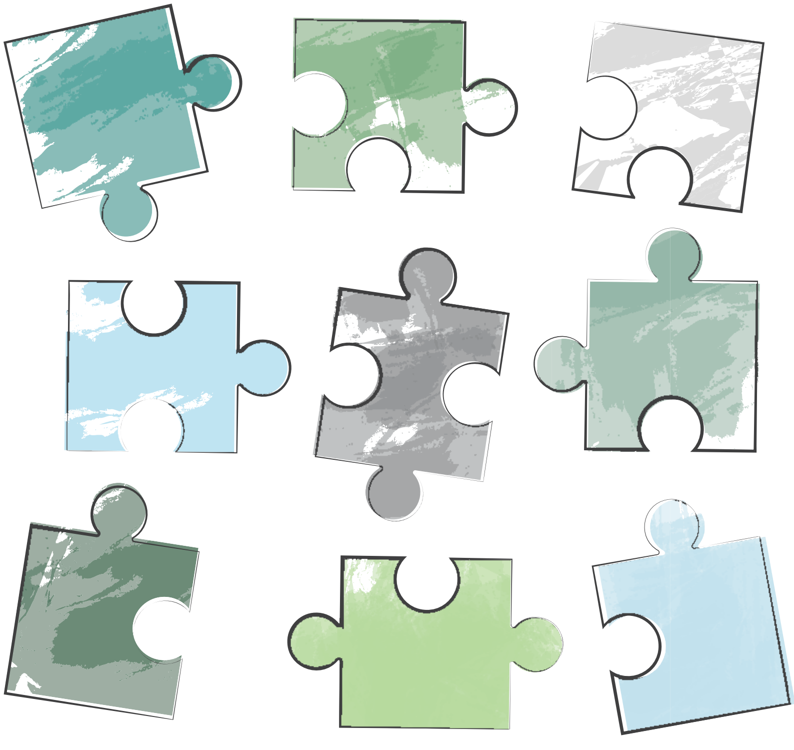
4.7 | CONCLUSIONS

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

- SuDSbury can educate citizens about household SuDS, with the largest improvement observed in knowledge acquisition and comprehension of what household SuDS are and their function.
- SuDSbury influenced personal norm stances to be more agreeable with household SuDS adoption by raising awareness of SuDS and their role in flood risk reduction.
- SuDSbury appealed to the players. Further improvements could emphasise the meaning and realism of the serious game by capturing ground infiltration more realistically for better comprehension of urban drainage concepts.

- Prior understanding of public awareness and knowledge concerning specific learning objectives would allow to better target the game to individual or group-level learning needs, increasing its impact.
- The game design process was far more circular and iterative than expressed by Peters and Westelaken (2014).
- The pre-/post-test evaluation design was easy to administer and able to establish the game effects. It should be refined to reduce potential response biases and improve the measurement of knowledge acquisition.

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



5

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

This chapter is based on: Mittal, A., van der Werf, J. A., Scholten, L., & Kapelan, Z. (2025). The Urban dRain game: Co-developing stormwater management solutions at neighbourhood scale. *Blue-Green Systems*, 7(1), 188–209.
https://doi.org/10.2166/bgs.2025.047

ABSTRACT

As cities expand and land becomes built over, more stormwater 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 sociotechnical 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.

5.1 | 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 (Sušnik et al., 2015; ten Veldhuis et al., 2010). Climate change affects precipitation patters, 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., 2017a).

Engaging relevant actors in the design and planning process is beneficial. When citizens are involved early on the process there concerns can be heard and they are more eager to accept the solutions and maintain them (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). 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). Another limitation of these strategies is that they may fail to effectively engage participants or be 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 chapter, 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 chapter is structured as follows: The next section presents the goals of the Urban dRain game, and case study context for which it was developed, followed by design considerations and the underlying decision-support tools. Section 5.3 presents the Urban dRain game concept along with details on game storyline, player roles, and the progression of rounds. In Section 5.4 , results from gameplay sessions with 70 MSc. students are presented. Section 5.5 discusses the results, improvements to the game and suggestions for further generalization of the game. Finally, Section 5.6 sums up the conclusions drawn from the game design and testing and provides a summary of future work.

5.2 | 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; Mittal et al., 2022; Peters & Westelaken, 2014): 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, the gaming world, and the learning that players can derive from the game (Harteveld et al., 2010).

The overall aim of the Urban dRain game is to enable 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 (Phase 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 for other case studies.

5.2.1 | Urban flooding context in the Netherlands

The Netherlands is one of the leading countries in Europe for urban sprawl, densification, and amount of surface covered by urban area (Claassens et al., 2020; Evers & van Schie, 2019). 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 implementation of blue-green solutions in urban areas (Hegger et al., 2017b; Ministry of Infrastructure and Water Management, 2022). In the Netherlands, municipalities are responsible for urban water management in the public areas, encompassing stormwater collection and processing, while private land owners bear the responsibility for stormwater 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., 2017b). 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 5-1, 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 5-1 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 Sections 3.3, 3.4, and Mittal et al., in preparation 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.

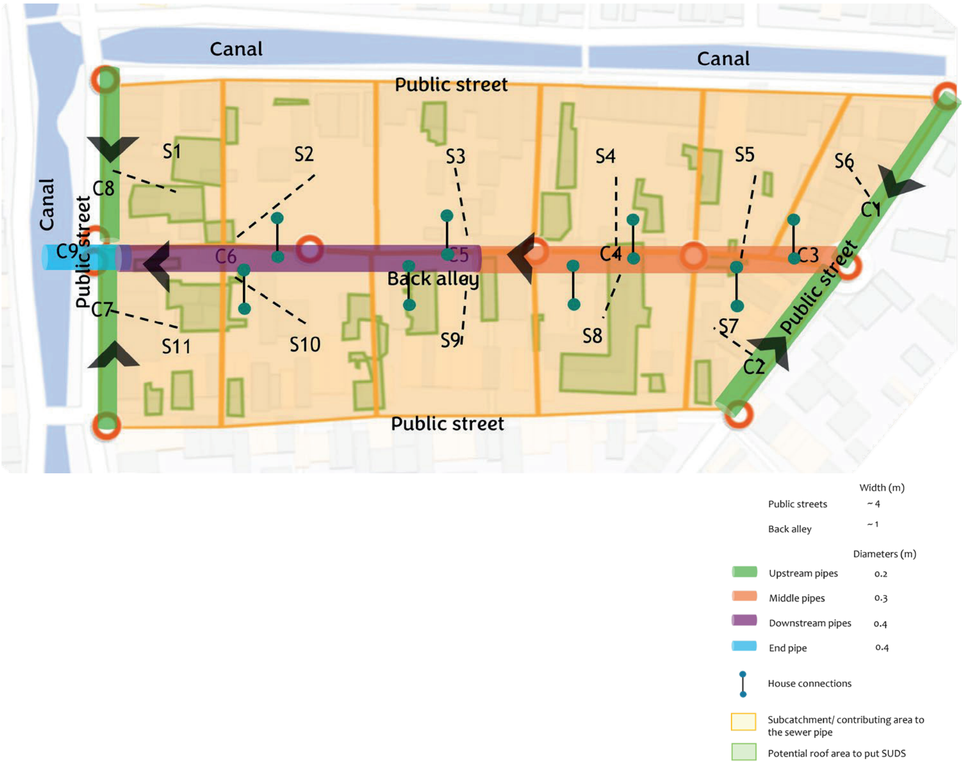


Figure 5-1: Base case infrastructure in the case study area

5.2.2 | 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 Sections 3.3, 3.4 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 in 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 area while others prioritise cost-effectiveness. Similarly, the municipality is composed of multiple departments, each with their 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 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.

5.2.3 | Decision support tool

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 Supplementary material B in Mittal et al., 2024c for pictures). The first two sheets are focused on the first phase of the game where municipality and residents look independently from each other at sewer system options and SUDS, while the third sheet is focused on developing a collective storm water 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 5-1) 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 5-2). 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 5-1). 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 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).

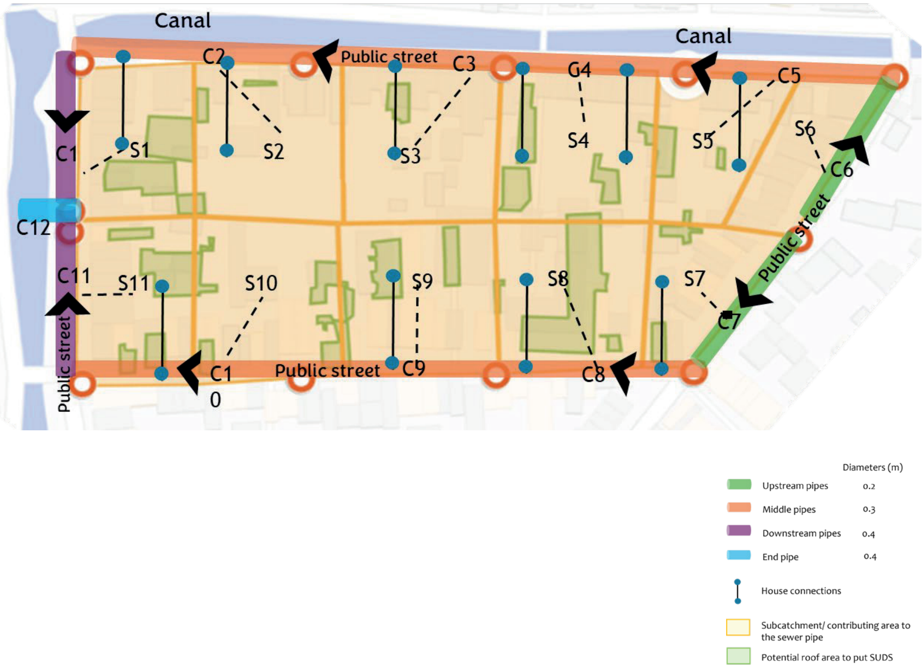


Figure 5-2: Second option for the layout for putting new pipes in the public street.

Hydraulic modelling of sewer options and SUDS

A simplified 1-D 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, the peak runoff calculated through the Rational method (Butler & Davies, 2004; Kuichling, 1889; Lloyd-Davies, 1906). The peak inflow at the downstream end of the whole area can be calculated using this method as follows:

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

where imax 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 5-1. 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 supplementary material B.2 in Mittal et al., 2024c). 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 supplementary material B.2 in Mittal et al., 2024c). 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 5-3). 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.

Table 5-1: Performance indicators to evaluate sewer and SUDS options (see supplementary material B.3 and B.4 in Mittal et al., 2024c for details about the underlying data and methodology used for calculation).

Indicators	Units	Assessment
		Sewer options
Investment cost	Euros	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	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 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 blue-green area added	--	Ratio of added green and blue-green areas compared to total grey area that can be potentially covered with SUDS

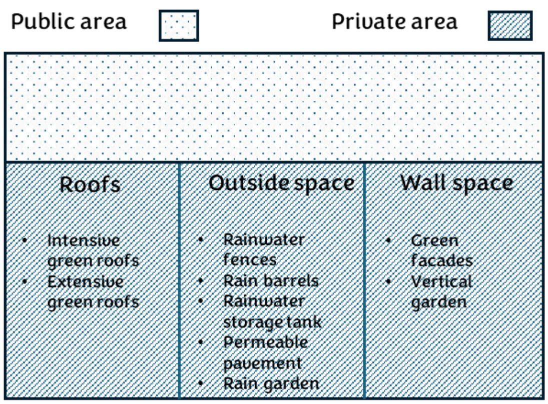


Figure 5-3: Division of available private area per sub-catchment and corresponding SUDS to be implemented in the game

5.2.4 | 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 5-2. The first two sessions were focused on testing the prototype game play 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 (GDPR) norms. These were approved by the TU Delft Human Research Ethics Committee (approval no. 3287).

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 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 hours 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 (ICUD). 8 participants were researchers and 3 represented Dutch water utilities. This session lasted 2.5 hours, 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 supplementary material C in Mittal et al., 2024c). 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.

Table 5-2: 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 previous session
6th June 2024	Internal play-testing of prototype with PhD researchers	4	--
12th June 2024	Play-testing advanced prototype at International Conference of Urban Drainage Followed by iterations within 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 survey 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 implementation of SUDS with the inflow to sewers. • Making residents and municipality 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

Validation of the final prototype

Once the identified issues were ironed out and iterative improvements had led to a mature game, which constituted the final prototype. The main change being that the residents and municipality to focus attention only 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 4 teams of 8-9 participants.

A post-game digital questionnaire was deployed to collect feedback on player's learning and gameplay experience (see Supplementary material D in Mittal et al., 2024c). 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?

49 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.

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 7 researchers from TU Delft who had not earlier been involved /played the game. The insights from the play-test session are also presented in the Results section.

5.3 | URBAN DRAIN GAME

5.3.1 | 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 stormwater 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 Supplementary material E (Mittal et al., 2024c).

5.3.2 | 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 four to five players. Players then select a specific role within the sub-group (see Figure 5-4 for example of a role card and Supplementary material F in Mittal et al., 2024c 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 5-4: Example of role cards in the Urban dRain game

5.3.3 | Rounds and progression

After the setup, the game progresses as shown in Figure 5-5. Players begin with Round 1, where residents and municipality 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 Figure 5-1 and Figure 5-2). Meanwhile, the residents look at the SUDS they can implement on private land including roof area, outside space, and wall spaces (see Figure 5-6). 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 minutes to familiarise themselves with the solutions, input them in their respective Excel sheet and explore their impacts.

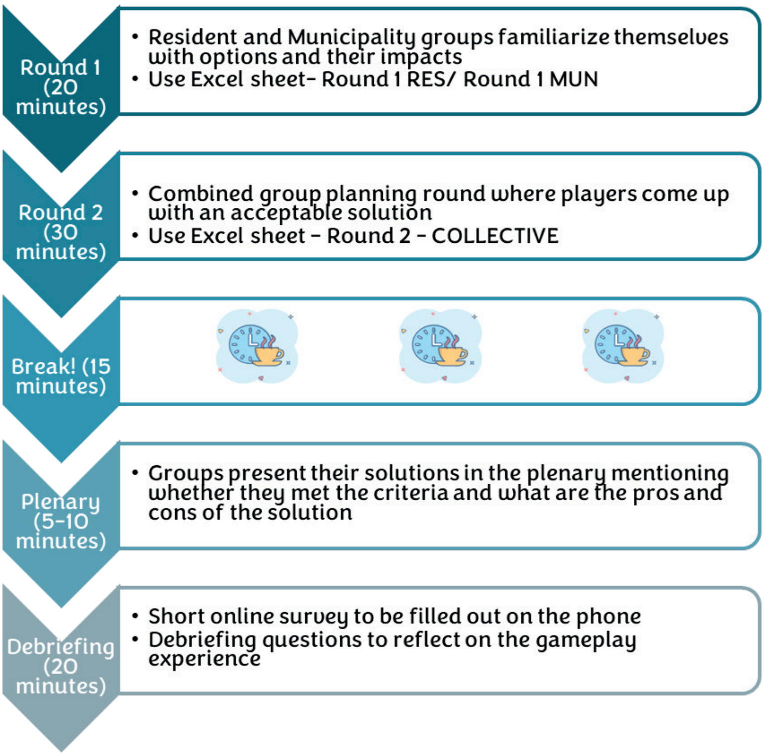


Figure 5-5: Progression and round in the Urban dRain game

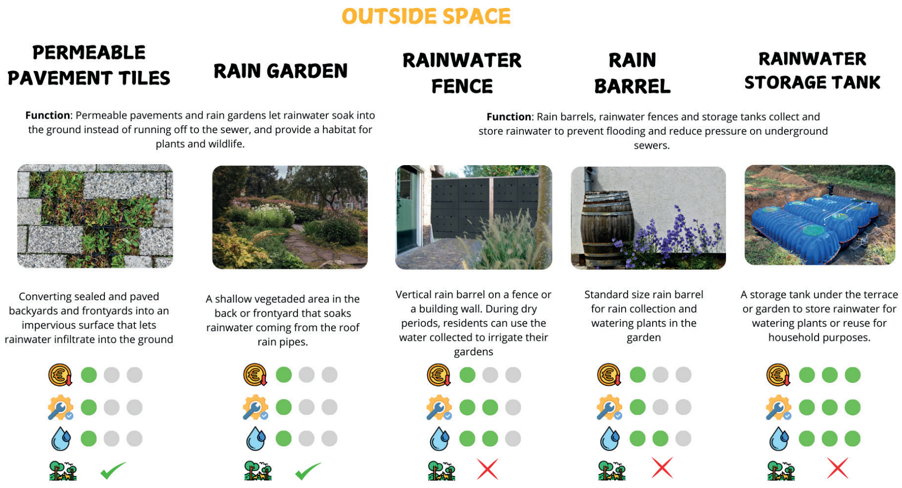


Figure 5-6: Example of a SUDS card

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 minutes to repeat the planning exercise. This time, they must collaboratively develop and negotiate the solution using the collective Excel sheet (see Figure 5-7) 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 upgrading 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
- A minimum area coverage of 20% with blue-green solutions
- Agreement on the distribution of costs

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

Figure 5-7: Collective Excel sheet to support decision-making in Round 2

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
1 Rainwater storage tank	0

Upstream pipe diameter (m)	Middle pipe diameter (m)	Downstream pipe diameter (m)	End pipe diameter (m)
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
1 Rainwater fence	0
1 Rain barrel	0
1 Rainwater storage tank	0

	Upstream pipe diameter (m)	Middle pipe diameter (m)	Downstream pipe diameter (m)	End pipe diameter (m)
Existing system	0.2	0.3	0.4	0.4
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					

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.

5.4 | GAMEPLAY RESULTS

Figure 5-8 (left) shows the game play 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 Supplementary material G (Mittal et al., 2024c).

Figure 5-8: Game play sessions in action (left – game session with 70 MSc. students and right – testing the last iteration of the game concept)

5.4.1 | Solution strategies

All teams achieved zero flood damage. Budgets ranged from €942,000 to €1,493,000, with higher expenditures correlating to a 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 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.

5.4.2 | 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 5-9).

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).

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'.

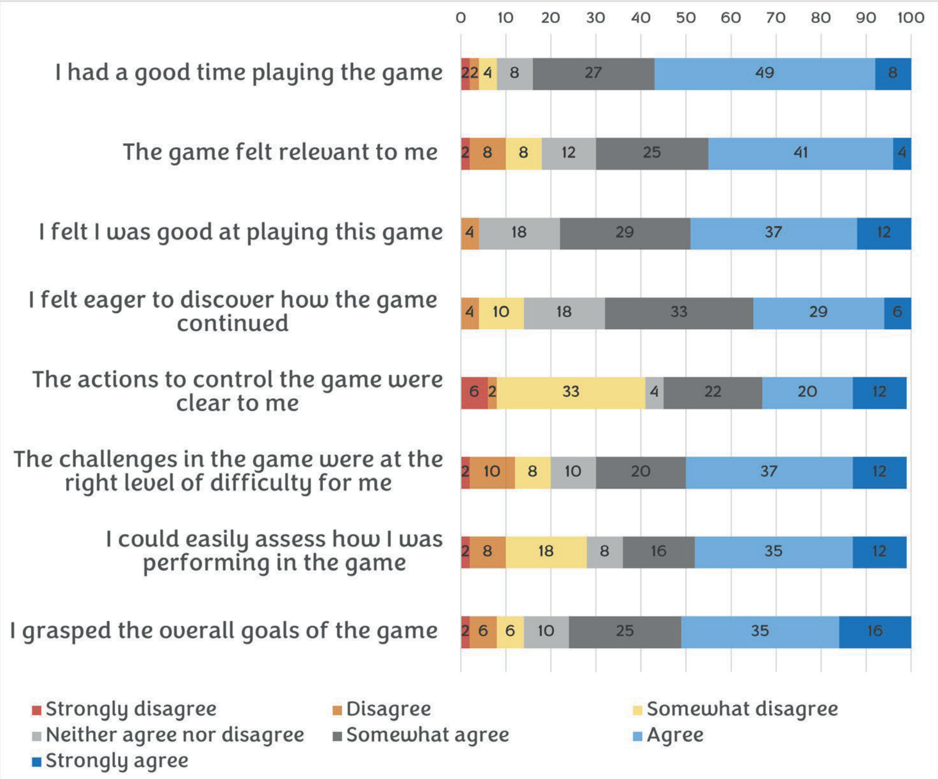


Figure 5-9: Responses to Likert-scale questions related to game experience in the post-game survey (n=49). Percentages have been rounded to the nearest integer.

5.4.3 | Learning and awareness

Figure 5-10 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.

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.

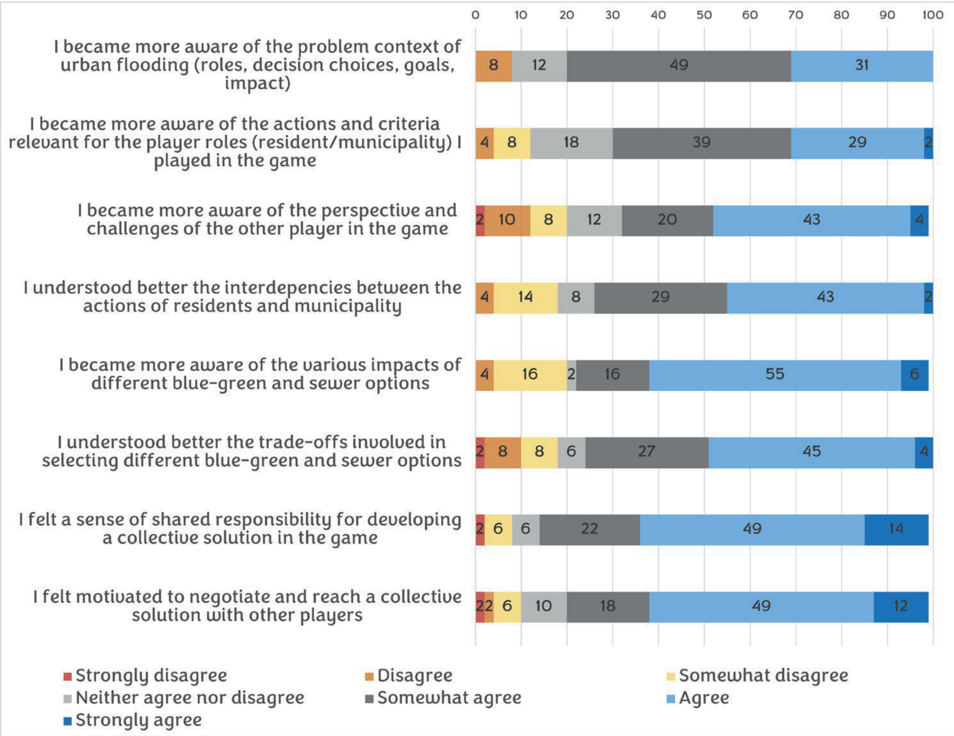


Figure 5-10: Responses to Likert-scale questions related to learning and awareness in the post-game survey (n=49). Percentages have been rounded to the nearest integer.

5.4.4 | 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 theSupplementary material H (Mittal et al., 2024c). The seven TU Delft researchers who assisted with post-validation gave it an overall rating of 4.3 (see Figure 5-8– right and see Supplementary material H in Mittal et al., 2024c 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.

5.5 | DISCUSSION

5.5.1 | 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 (Savic, Morley, and Khoury 2016) 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 roleplaying 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.

5.5.2 | 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 5.4.3.

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.

5.5.3 | 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 systems analysis should be done using the following guiding questionsClick or tap here to enter text.:

- Who are the key actors, 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, minigames 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.

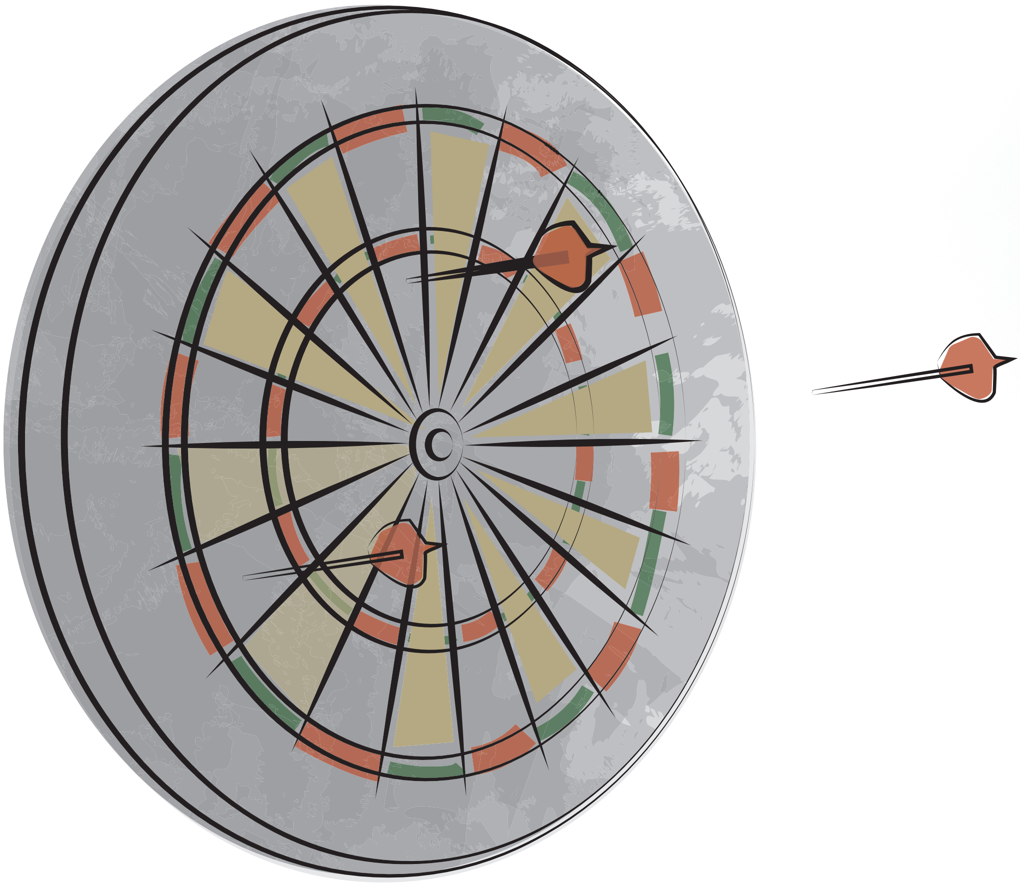
5.6 | CONCLUSIONS

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.



6

Conclusions and outlook

6.1 | SYNTHESIS OF FINDINGS

As cities become more impermeable, they become more prone to pluvial flooding. Ageing sewer infrastructure along with increasing urbanization and climate change will lead to high runoff and may deem existing sewer capacities insufficient. The problem of stormwater management is complex, consisting of multiple actors, each with their own perspective, objectives, solutions that should be adopted and perceived uncertainties. To achieve effective stormwater management, it is important to address the underlying decision-making challenges faced by the actors involved. Within the scope of this thesis, two problems were identified to be addressed using serious games. Firstly, a lack of awareness about the urgency and risk of urban flooding and associated SUDS among urban residents. Secondly, a lack of decision-support tools that bring public and private actors together to collectively plan and co-create solutions for flood-proof neighbourhoods. To address these problems, this thesis aims to test the potential of serious games to improve the decision-making of both private and public actors for better stormwater management in urban areas. The main research question posed in this thesis was:

How can serious games be ***designed*** *and* ***used*** *to* ***improve decision-making*** *for stormwater management?*

The findings for the key elements of this question are synthesized below:

6.1.1 | Design of serious games

Serious games for stormwater management can be designed by adopting a design approach that explicitly takes into account both the technical and multi-actor aspects of the problem. Furthermore, given urban areas are becoming more dense with increasing residential land use, serious games focused on supporting stormwater management should involve both private and public actors. To ensure that the multi-actor nature of the pluvial flooding problem is incorporated into the design of serious games, actor mapping and cognitive mapping methods were found to be highly valuable.

In Chapter 3, an in-depth systems analysis methodology was presented to conduct the initial problem analysis phases of serious game design. Two serious games – SUDSbury and Urban dRain were designed to address the decision-making needs of stormwater management actors broadly following this approach. The methodology ensures that the perception of multiple actors involved in the development and adoption of stormwater management solutions is incorporated. It supports the systematic translation of the pluvial flooding context into a conceptual systems map with elements such as actors, their goals, solutions, and perceived uncertainties. The systems map can be further used to select an appropriate problem scope and translate the elements of the systems map into elements of a serious game such as roles, goals, scoring, actions, and events.

After scoping the problem that will be addressed in the serious game, iterations are needed to make the game playable, manage play time, and ensure that the game is complex enough while not deviating from the key message and intended learnings of the game. Design choices that were found to align with the pluvial flooding problem in both SUDSbury (Chapter 4) and Urban dRain (Chapter 5) games incorporated providing players with both competitive and collaborative sides of the problem; providing individual and collective goals to players, and highlighting trade-offs among these goals. Given that the games were developed to be played with urban residents who may have little to no background in stormwater management, emphasis should be given to simplifying technical information about the SUDS and sewer options included in the game.

6.1.2 | Use of serious games

The serious games developed to support decision-making for stormwater management can be used and tested with the general public, students and stakeholders involved in the problem. Although the games in this thesis were designed to be played with real-world actors, this could only be partly achieved. SUDSbury was tested with 14 urban residents in Delft, which is a small and limited demographic sample. Similarly, although Urban dRain was developed for a case study, the game was instead tested in an educational setting with 70 MSc students. This limits the validity of the conclusions drawn from the game and more systematic testing is required with the target audience.

Different approaches can be followed to test and understand the impact of the serious games developed in this thesis. SUDSbury was introduced as a stand-alone intervention with a pre-game survey, a gameplay session, and a post-game survey. Urban dRain was embedded into an MSc. programme activity, where gameplay sessions were conducted followed by a post-game survey.

To use and implement serious games, a few guidelines can be extracted from the work done. Firstly, before implementing the game, it is critical to conduct validation sessions with both experts and non-experts in the subject area to ensure that both the technical problem is well represented and the intended learnings are adequately transferred to players who are new to the subject. Iterating on the initial results received from these sessions helps improve the balance between the play and learning aspects of the game. Secondly, while testing the game with the intended audience, it is important to ensure that the game and relevant problem are introduced without divulging too much information and that along with a facilitator, a dedicated note-taker is arranged to document the proceedings of the game session. Thirdly, although playing games is meant to be a voluntary activity (Huizinga, 1980; McGonigal, 2011; Michael & Chen, 2006) undertaken for fun and engagement, finding participants to test serious games is challenging and requires widespread recruitment activities or budgeting funding for incentives. Lastly, to ensure that serious games can be used and tested with practitioners involved in stormwater management, research projects should be set up in a way that there is dedicated access to stakeholders and that co-creation and testing of the game are integrated into pilot projects.

6.1.3 | Improving decision-making for stormwater management

The goal set out in this thesis was to improve stormwater management decision-making through the use of serious games. However, conceptualizing what constitutes an improvement in decision-making and assessing it was challenging. To narrow the overall problem scope, two specific decision-making contexts/problems were shortlisted to be supported with games: lack of awareness about SUDS among private residents and lack of integration of actor perspectives to foster collaboration among actors involved in stormwater management. For SUDSbury, improvement in decision-making was conceptualized as forming an intention to implement household SUDS after playing the game. For Urban dRain, it was conceptualized as an improved understanding of the need for cooperation among actors and iterating and developing a suitable mix of blue, green and grey solutions.

Within the scope of the gameplay, conclusions can be drawn that players' decision-making improved towards achieving the goals set out within the game. For instance, players playing SUDSbury gradually implemented more SUDS in the game and a comparison of pre-game and post-game questionnaires showed that they were more aware of SUDS and their functions and developed an intention to implement them in the real-world. Similarly, players who played Urban dRain negotiated and cooperated to develop and continuously improve a collective solution for the neighbourhood by combining blue, green and grey solutions. Moreover, it can also be concluded that by playing serious games, players learned about both the technical and social aspects of stormwater management. They learned about different SUDS and sewer options and their associated impact, and the broader complexity of the decision problem: actor dependencies, and financial and climate-related uncertainties.

However, whether gameplay behaviour and learning go beyond the gameplay cannot be concluded. A decision-maker goes through multiple stages in behaviour change from the formation of an intention to adoption of a new behaviour (Bamberg, 2013). From the field of behavioural science and psychology, we know that humans are boundedly rational and even if we have the awareness and information about a decision-making context, our decisions are impacted by cognitive biases (Ellis, 2018; Kahneman, 2013). Additionally, there could also be other barriers at play which were not taken into account in the games developed. For instance, practical considerations such as lack of subsidies, space, or ownership rights for SUDS adoption (O'Donnell et al., 2017; Roy et al., 2008) or power dynamics, groupthink and lack of trust that may impede decision-making in group settings (Spetzler et al., 2016; van Stokkom, 2005). Hence, whether learnings from the SUDSBury and Urban dRain game translate into real-world decision-making remains to be studied.

6.2 | ANSWERING RESEARCH QUESTIONS

6.2.1 | RQ1: What are the knowledge gaps in the decision support and design of current serious game applications?

From a review of 15 serious games designed to support urban water management decisions, I found that there is a lack of serious games designed to support decision-making for stormwater management explicitly. In light of these gaps, two serious games were designed in this thesis to support the decision-making of public and private actors focusing on increasing awareness of the problem context of urban flooding, stimulating cooperation among actors while also allowing for the combination and assessment of blue, green and grey solutions. Furthermore, most serious games that were reviewed primarily focused on supporting later phases of decision-making, such as evaluating alternatives or implementing solutions, while neglecting earlier, foundational stages such as problem structuring and defining objectives. In terms of the design approach followed by these games, there was a lack of a structured process to select the problem scope and translate the problem context of urban flooding into the game world. These gaps were taken as the foundation for the research presented in Chapters 3, 4 and 5 in this thesis.

Furthermore, while assessing the design elements of current UWM game applications against the success factors of serious games, it was found that most games lack features such as detailed backstories, dynamic narratives, and adaptive difficulty levels. These elements can significantly enhance player engagement and learning outcomes by creating a more immersive, customized gaming experience. These aspects were partly incorporated into the design of the serious games presented in Chapters 4 and 5 by introducing the problem context of pluvial flooding and creating a story around a fictional, yet relatable town, within the Dutch context that needs to be protected from flooding. In terms of evaluating game outcomes, the review revealed that current game applications predominantly employ single-group post-test research designs, which are limited in their capacity to establish causal relationships between game interventions and observed impacts. To improve the rigour and reliability of these evaluations, controlled research designs, such as randomized controlled trials (RCTs) can be adopted, along with clear indicators of decision quality.

6.2.2 | RQ2: How can the multi-actor complexity of stormwater management be incorporated into the design of serious games

To incorporate the complexity of the urban flooding problems into the design of a serious game, a new methodology was proposed in Chapter 3 combining actor analysis and cognitive mapping. The methodology helped visualize the perceptions of induvial actors, and the relations between actors, goals, and uncertainties in the overall system. Furthermore, starting from an initial problem statement, it helped surface specific issues that could be addressed in the game, actor-level dilemmas, and shared goals among all actors. Conducting a system analysis following this methodology can aid game designers in systematically assessing the real-world problem and translating it into a serious game. Key steps/guidelines underlying the methodology pertaining to the game design process and the urban flooding context were found to be:

- Instead of directly jumping into possible game ideas and designs, game designers must take a step back and analyse and scope the problem that needs to be supported via the game.
- Take into account the multi-actor nature of the problem and identify both public and private actors relevant to the decision-making context.
- Take the perspectives of the identified actors into account; their goals, perceived solutions, and uncertainties and understand how these causally relate to each other.

- Incorporate not just the technical solutions into the game but also the interdependencies among actors to implement those solutions.
- Take into account that in addition to collective goals, actors have their own individual goals and often a trade-off and negotiation are required among these goals.
- While looking at the solution space, give players the degree of freedom to combine different blue, green and grey solutions and learn what is a suitable mix for their case.

Although the methodology provides a structured way to analyse the problem of urban flooding, it cannot be concluded if a structured design process leads to a quicker design process or a better/more valid game. The game designer is faced with the choice of either doing a quick problem analysis or doing an in-depth problem analysis. The latter may consume more time early on but has a foreseeable advantage in avoiding multiple iterations of the game. Another limitation of the method is that it is conceptualized from the perspective of a game designer/researcher gathering inputs from the relevant stakeholders, which was largely the research setup for this thesis. However, an alternative approach is to follow a participatory design process wherein the game designer is part of a team that also consists of end users/players, subject-matter experts, practitioners, problem owners, software developers and/or graphic designers (Pacheco-Velazquez et al., 2023; Wanick & Bitelo, 2020). Joint workshops can be held with the design team to collectively build cognitive maps or conduct a group modelling session (e.g. Bassi et al., 2015; Ducrot, 2009) to define the problem. Adapting a participatory design process may improve the systems analysis methodology proposed in this thesis as the overall conceptual systems map would be validated by the actors involved in the problem context.

6.2.3 | RQ3: How can a serious game educate urban residents about household SUDS?

Serious games focusing on increasing awareness about the urban stormwater cycle and the associated risks of pluvial flooding among urban residents are missing. A new board game, SUDSbury, was designed and tested to address this gap. Players represented house owners and renters who had to implement SUDS to prevent the fictional neighbourhood of SUDSbury from flooding. Key elements of the game to impart learning were: (1) inclusion of SUDS options and simplified information about their pros and cons (2) trade-offs among costs, flood-risk reduction and liveability, (3) increasing climate change impact and progression of in-game challenge to prevent flooding, and (4) combination of competition and collaboration within the game.

A pre/post-test design was used to measure the game's impact, and the game was tested with 14 participants. Based on the playtest results, there was an increase in the participants' average knowledge and comprehension after playing the game. Additionally, players developed a personal norm or an intention to adopt SUDS and implement them in their households. The results of the game were consistent with the Stage model of Self-regulated Behavioural Change (SSBC) that posits that enhancing problem awareness and making players aware of the consequences of their actions can help them develop an intention to act sustainably (Bamberg, 2013). After playing SUDSbury, players developed an intention to implement SUDS. However, since the game was focused on the early stages of decision-making and behaviour change process, developing an intention may not result in long-term behaviour change. The limited sample size further makes it difficult to draw valid conclusions and compare the observed effect sizes with other serious game interventions (Smith et al., 2015) or applications of the SSBC model (Keller et al., 2019).

Overall, SUDSbury was rated well on aspects of the gameplay experience. The game was simple enough for players to understand with clear rules and easy-to-follow instructions. However, the realism of the game needs further improvement participants suggested adjusting the sewer capacity and providing a more accurate representation and distinction between the function of different SUDS – storage vs infiltration.

6.2.4 | RQ4: How can a serious game foster collaboration among actors involved in stormwater management in Dutch neighbourhoods

Platforms to bring stakeholders involved in stormwater management together are scarce. Those that exist only focus on the perspective of a single decision-maker neglecting the (potentially) conflicting perspectives of multiple actors. A new game, Urban dRain was developed to bring public and private actors together to co-develop a stormwater management plan for a Dutch neighbourhood, focusing both on social and technical aspects of the pluvial flooding problem. To achieve this, key elements of the game were: (1) division of players into private and public actors with their respective group budgets, (2) assignment of an overall collective goal while also an individual role, perspective and goal to each player, (3) consolidating blue, green and grey solutions within one underlying hydraulic model, (4) assessment of solutions across multiple criteria through a simplified Excel tool, and (5) implementation of the game as a tournament to stimulate competition among the teams and cooperation within the teams.

The gameplay results show that the game was successful in bringing people together, helping them adopt a specific role, and initiating negotiations among them. Players reported high levels of awareness about the context of urban flooding and developed a sense of shared responsibility and collective problem-solving. The results also show that the game supported technical learning about the combination of SUDS and sewer options. All teams managed to meet the winning conditions and came up with different strategies to combine sewer upgrades with blue and green solutions and distribute costs. The game was rated highly on aspects of fun, relevance, and ability to play the game while aspects related to the usability of the underlying Excel sheet were rated relatively low.

Similar role-playing games have been designed to stimulate cooperation among actors involved in water management (Bassi et al., 2015; Ferrero et al., 2018; Gomes et al., 2018; Hill et al., 2014; Zhou et al., 2016). Given the different learning goals of these games, comparison of game outcomes is difficult. However, considerations for further improvement of Urban dRain can be derived such as introducing another round with a worse climate-change scenario (Ferrero et al., 2018), improving the assessment of the final solution by combining voting and expert judgement (Hill et al., 2014), and including actors with lesser influence such as NGOs or infrastructure companies as players (Ferrero et al., 2018).

The case study used as the basis for the Urban dRain game design represents an stormwater management problem with an atypical sewer design in the back alleys which is not common across the Netherlands. The game is limited in supporting the decision-making in the case-study area given much of the real-world complexity was simplified and aspects of groundwater level management and land subsidence issues were excluded.

6.3 | THESIS SCIENTIFIC CONTRIBUTIONS

Through this thesis, the following contributions were made to the current scientific literature:

- Developing a methodology for serious game design that helps shortlist relevant actors, understand their perceptions about the problem of pluvial flooding and synthesize those perceptions into a systems map.

- Designing and testing the prototype of a generic serious (board) game called SUDSbury that raises awareness about pluvial flooding and associated solutions among urban renters and home owners.
- Designing and testing the prototype of a case-specific serious game called Urban dRain that brings multiple actors together to co-develop a stormwater management solution at neighbourhood scale
- Developing a simplified Excel-based decision-making tool to enable assessment of blue, green and grey solutions to pluvial flooding.
- Review and comparison of existing serious game applications designed to support urban water management decisions and analysis of often overlooked aspects that lead to biased game applications to gamified simulation models rather than well-designed serious games.

6.4 | RECOMMENDATIONS

This thesis has contributed to a better understanding of how serious games can be designed and used to support decision-making needs in stormwater management. However, future research is recommended on the following overarching topics:

6.4.1 | Increase the validity of the systems analysis methodology and establish a relation between game design process and outcome

To improve the application of the cognitive mapping methodology, the individual and combined cognitive maps could be developed collectively in workshops rather than derived from individual interview data. In addition to relevant actors, subject-matter experts on civil engineering, urban planning, and ecology can also be included in the map creation process to ensure completeness. Furthermore, there is potential in the serious gaming literature to establish a link between the game design process and the outcome. The question remains open: does following a structured process result in a better game—one that is more aligned with the real-world problem, realistic, and effective in achieving its learning goals? Future work could focus on comparing different design processes – more structured vs intuitive and compare the quality of the game outputs.

Another avenue for exploration is the development of a comprehensive framework linking game mechanics and elements to common game goals. Such a framework would help designers avoid reinventing the wheel, particularly researchers who lack a background in serious games or formal training in design. Additionally, a platform where serious games are organized and tagged based on their themes, mechanics, target audience, or format will be a useful starting point for game designers and researchers.

6.4.2 | Aim for a complete portrayal of the functions of SUDS

The games developed in this thesis were focused on increasing awareness about different types of SUDS, their basic functions and underlying costs. Given low levels of current awareness, more focus was given to presenting the co-benefits of SUDS with little attention to the associated challenges for their successful implementation. These challenges, e.g., space requirements, regular maintenance, limited lifespan, roof reinforcements, water logging and potential mosquito proliferation can be incorporated in further iterations of the games to portray a complete picture of SUDS (Charlesworth et al., 2003; Valdelfener et al., 2019).

Similarly, the sustenance of SUDS during periods of drought remains an open-ended question, as the current irrigation needs of SUDS can lead to the overuse of drinking water (Andrusenko et al., 2024). The seasonal water requirements of SUDS need to be further investigated so they can provide co-benefits – promote water storage, infiltration and biodiversity during periods of heavy rainfalls and support temperature regulation during periods of drought. Further iterations of the game need to better incorporate periods of drought and the performance of SUDS with changing seasons. More awareness on how to maintain the SUDS with changing seasons can also be incorporated into the games.

6.4.3 | Adapt the games further to improve application in different contexts

To increase the relevance and realism of SUDSbury for urban residents, it could be modified to incorporate decision-making within homeowners associations since decisions regarding implementing solutions on common spaces in a residential building are made collectively (Rijksoverheid, n.d.). Additionally, more real-world trade-offs could be introduced, such as competing uses for roof space (e.g., solar panels or combinations of solar panels and green roofs, as suggested by van der Roest et al., 2023) and the impact of current subsidies on realistically implementing these solutions. Similarly, Urban dRain can be expanded to include the perspectives of actors such as the water board, NGOs, and urban planners. Furthermore, another round can be added in the game where the collective solution is further interpreted in individual groups and discussions are initiated on fair cost distribution issues and maintenance responsibilities within the groups.

The games can be further adapted to be implemented in new case studies. Given SUDSbury's generic design, it can be played within the Netherlands and in a context similar to the Netherlands with minimal adaptation. In contrast, adapting Urban dRain for new case studies would require more effort. The underlying systems analysis done for the game must be performed again for implementation in a new context by mapping the relevant actors, objectives, infrastructure specificities and rules and regulations in the new case study. In addition to that since the game was designed for a specific case study with a current sewer design that is atypical, the game represents a more complex system than what can be found in most cities across Netherlands. However, the overall structure and storyline of the game can still be applied to other cases by stripping away the complexity of back-alley sewer systems and focusing on upgrading and resizing sewers in public areas/streets in combination with private property measures to implement SUDS.

6.4.4 | Establish game impacts with more systematic evaluation

Future work should focus on systematic testing of the game by increasing the sample size to establish the validity of the game's impact. For instance, SUDSbury should be tested with a broader demographic, including varying ages, educational levels, and types of homeownership. To overcome the challenge of finding participants, recruitment can be facilitated through sustainability networks or municipal citizen engagement initiatives. Incentives or vouchers can be given to participants for their time, and this would require portioning out a significant part of the research budget for participant recruitment. This has been an effective strategy in recruiting more than 150 urban residents to test the SUDSbury 2.0 game (Scholten et al., in preparation). Furthermore, control groups could be setup to compare the impact of the game in comparison to other forms of education such as watching an instructional video or reading a flyer. Furthermore, a key challenge in evaluating game interventions such as *Urban dRain*, developed for a specific case, is the limited sample size of real-world actors to play the game. In such cases, qualitative methods such as post-game interviews and detailed debriefings should be used to assess the impact of the game.

6.4.5 | Incorporate serious games into real-world initiatives and decision-making processes

To ensure that testing the games in real-world settings is successful, they should be incorporated into the wider decision-making and citizen engagement process. Many municipalities in the Netherlands have ongoing greening initiatives and plans to make cities rainproof in the near future (Dai et al., 2018; Stobbelaar et al., 2021). These take the form of pilot projects or creating awareness through information about subsidies for greening neighbourhoods through websites, information brochures, or newspapers. Serious games can be used in combination with these initiatives and be used as part of the portfolio of engagement measures. For instance, SUDSbury can be played in the initial phases of citizen engagement to increase awareness levels among residents about the problem of urban flooding and thereafter more information can be provided on specific subsidies through information brochures. Similarly, Urban dRain can be played at the start of pilot projects in neighbourhoods where sewer upgrades are planned to involve multiple actors, understand their preferences, and co-develop collective plans.

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About the Author

Aashna Mittal was born in Ludhiana, India on 21st August, 1992. She completed her schooling there and then moved to Pilani, Rajasthan to pursue a bachelor's degree in Electronics and Instrumentation engineering from the Birla Institute of Technology and Science. After her bachelor's degree, she worked as a software engineer designing embedded systems for warehouse robots.

Drawn to bigger societal challenges in a developing country, she transitioned to studying liberal arts in 2016 by pursuing the Young India Fellowship. There she developed an interest in public policy, which further took her to the Netherlands in 2017 to do a master's in Engineering and Policy Analysis from TU Delft. She graduated with a cum laude and left with a growing curiosity about water issues, the "human" side of a technical problem, and how we make collective decisions about shared resources.

This eventually led her to pursue a Ph.D. at TU Delft, where she designed and tested serious games – games that not only entertain but can also make us learn about complex problems in a fun way. She co-developed three serious games during her PhD trajectory: (1) AgriLemma – aimed at increasing awareness of sustainable agriculture solutions among farmers, (2) SuDSbury – aimed at increasing knowledge and awareness of urban residents about sustainable urban drainage solutions, and (3) Urban dRain – aimed at bringing municipalities and residents in the Netherlands together to negotiate and co-develop stormwater management solutions for their neighbourhoods.

Aashna's skills span qualitative methods such as serious game design and facilitation, conducting interviews, and building conceptual models. She is passionate about interdisciplinary research and strives to ensure that scientific research is linked to real-world problems. Since March 2025, she is working as a postdoctoral researcher in serious gaming at TU Delft. Outside work, you'll find her dancing and picking up new dance forms. Good food is the way to her heart and she is always up for a walk/coffee to discuss all things games, books, and art.

List of Publications

Peer-reviewed journal publications

Mittal, A., van der Werf, J. A., Scholten, L., & Kapelan, Z. (2025). The Urban dRain game: Co-developing stormwater management solutions at neighbourhood scale. *Blue-Green Systems*, *7*(1), 188–209. https://doi.org/10.2166/bgs.2025.047

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Mittal, A., Bekebrede, G., Kapelan, Z., & Scholten, L. (*Manuscript in preparation*). Taming system analysis in serious game design – a methodology combining actor analysis and cognitive mapping.

Scholten, L., **Mittal, A.**, Freese, M., Bekebrede, G., & Champlin, C. (*Manuscript in preparation*). Serious gaming to speed up urban climate adaptation? Shifts in cognitive-affective stances of Dutch residents towards adoption of household measures against pluvial flooding.

Hoffmann, R., Tamara, A., Dahal, B., **Mittal, A.**, Głogowski, A., Fialkiewicz, W., Nagy, A., Cavazza, F., Mengen, D., Georgen, K., Mustafa, S., Tang, Q., Schilling, O. S., Klöve, B., Kapelan, Z., Brunner, P., & Hendricks Franssen, H.-J. (*Manuscript submitted for publication*) Understanding the needs of agricultural stakeholders for the development of applicable integrated hydrological model outputs.

International conference contributions

Mittal, A., van der Werf, J.A., Scholten, L., & Kapelan, Z. (2024). Workshop titled The Urban dRain game: Facilitating cooperation between stakeholders through serious game to make urban neighbourhoods rain-proof. Delft, The Netherlands.

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European project contributions and publications

Tamara, A., Canet-Marti, A., Canga, E., Guerrieri, V., Amadori, S., **Mittal, A.**, Lavrnić, S., Hartl, M., & Nagabhatla, N. (2024). *Understanding Multifunctionality of Constructed Wetlands in Agricultural Settings in the European Region*. PB-2024-01. Bruges: UNU-CRIS

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