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A review of serious games for urban water management decisions: current gaps and future research directions

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ABSTRACT

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 paper, 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 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.

1. Introduction

The health and growth of a city are strongly interlinked to water. A city depends on urban water systems to collect, treat, manage, and distribute drinking water, wastewater, groundwater, surfacewater, 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 take 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 gray, 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 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 stakeholders, 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

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developed in the water sector to enable learning about complex problems and support decision-making (Aubert et al., 2018; Madani et al., 2017; Savić 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; Savić et al., 2016) reiterate the need to systematically study the design and evaluation of serious games in the water sector. In this paper, 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 above challenges, the following research questions are answered in this paper:

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 and 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 paper is as follows. In Section 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 3, the methodology to select and analyze relevant UWM games is presented. In Section 4, the mappings of selected games to decision-making and game design and evaluation phases are presented. In Section 5, gaps for future research are highlighted and the conclusions are presented in Section 6.

2. Serious games for decision-making

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 stakeholders each with their own objectives, values, and perceptions about the problem. Typical stakeholders include water utilities, municipalities, different government agencies and water boards, consultants and researchers, civil society, non-governmental organizations (NGO) among many more. These stakeholders 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 rainwater 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 tradeoffs. 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. 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 paper, we use the decision analysis lens to assess and analyze 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 tradeoffs 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 Savíc, 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 Fig. 1: (1) structuring the problem (2) defining objectives and attributes, (3) developing alternatives (4) estimating consequences of alternatives (5) evaluating tradeoffs 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 stakeholders, their key issues, values, uncertainties, and constraints, and then selecting the appropriate frame of the problem. To achieve decision quality in this phase, stakeholders must agree on a shared frame of the problem by discussing what is the decision problem being solved, how do different stakeholders 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. 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.

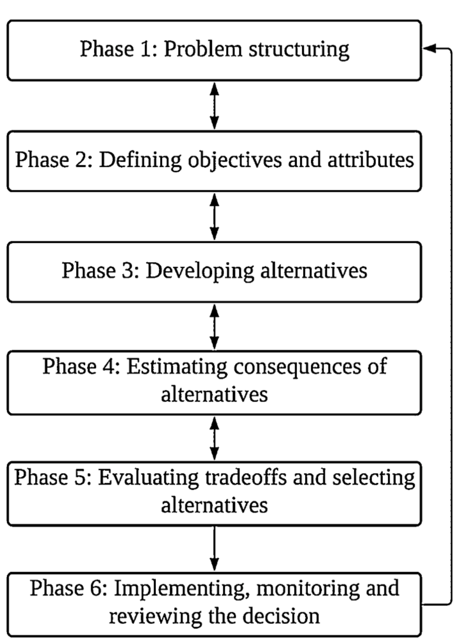

Fig. 1. Decision-making phases. Note: These phases may not proceed linearly and decision-makers may move back to previous phases, e.g., if at Phase 3 sufficient alternatives cannot be found, then decision-makers may move back to Phase 1 to broaden the scope of the problem.

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; Savić 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.

2.3. 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.

2.3.1. 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 Fig. 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 analyzed 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.

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).

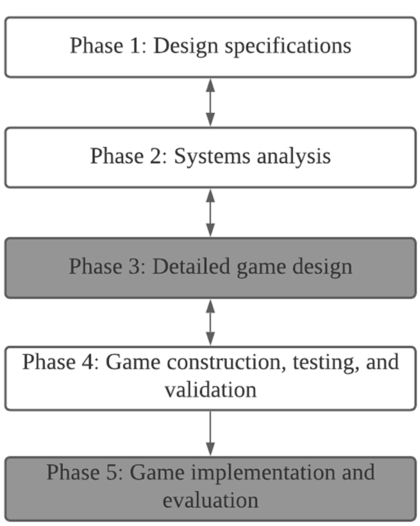

Fig. 2. Common serious game design phases. Phase 3 and Phase 5 are considered in detail in this paper as they are used to evaluate the detailed game design and evaluation approach of UWM games.

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 paper, we assess the detailed design (Phase 3) and evaluation (Phase 5) approaches of selected serious game applications with respect to best practices described above.

3. Methodology

3.1. Study selection

To answer the research questions posed in this paper, 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:

3.1.1. 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; Savić 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.

3.1.2. Selection criteria

To select games relevant for this paper, 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 2.3), 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 paper 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 provides additional information about the excluded games, including the reasons for exclusion. An overview of the 15 shortlisted games is provided in Table 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 2.3: decision-making, simulation, knowledge sharing, persuasion, data collection/exchange/exploration, motivation, or training.

3.2. Analysis

In this paper, each game presented in Table 1 was analyzed based on information available in the academic publication or by playing the game (where possible). For instance, the first author played the SeG-WADE 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 and 2.3.

3.2.1. 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.

Table 1
Overview of shortlisted UWM games.

Game No.	Game Name	Author	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	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 related hypothesis	Decision-making, knowledge sharing (informative)
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 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 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
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 integrated decision-making	Simulation, knowledge sharing (informative)

3.2.2. 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):
   - Learning goals: achievement of game objective (with or without explicit indicators).
   - Game design: mechanics, realism, rules, level of detail, aesthetics.
   - Game complexity: clarity and ease of understanding.
   - Player experience: ease of use, playability aspects, satisfaction.
   - Player engagement: interaction with user interface/players, enjoyment and fun.
   - Cognition and behavior: impact on player's emotions, mood, attention-level.

The results of the above analysis are presented in Section 4.

4. Results

4.1. Mapping serious games to decision-making phases

Table 2 presents the mapping of serious games reviewed in this paper to decision-making phases (see supplementary material B for more details).

A common observation across all games is that all phases of decision-making were not addressed in any game. 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 stakeholders 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 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 stakeholder consultations were used to develop a broader understanding of stakeholders' 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

Table 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

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 paper 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.

4.2. Assessing game design and game evaluation

Table 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 paper, 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

Table 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	-
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	-

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 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 paper 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 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 paper, 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. 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.

Table 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	Post-game debriefing session	Learning goals (no explicit criteria); game design

5. Future research directions

In this paper, 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.

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 stakeholders 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 stakeholders, 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, stakeholders, objectives, alternatives, and uncertainties (Ackermann, 2012; Mingers, 2011; Mingers and Rosenhead, 2004; Rosenhead, 1996).

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 paper 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 tradeoff 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).

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 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 paper 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 Högberg 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?

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 paper 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.

Conclusion

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 paper, 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 paper 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 paper has its limitations. Since only UWM games targeted at professionals were reviewed in this paper, the scope can be further extended to cover games targeted at students and general public (see supplementary material 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 paper, 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 paper.

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.

CRediT authorship contribution statement

Aashna Mittal: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization, Project administration. **Lisa Scholten:** Conceptualization, Methodology, Writing – review & editing, Supervision, Funding acquisition. **Zoran Kapelan:** Conceptualization, Methodology, Writing – review & editing, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

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