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C Senior[1], A Temeljotov Salaj[1], A Cepuran[1], M Gabriela Diaconu[1], A Johansen[1]

[1]Department of Civil and Environmental Engineering, Norwegian University of Science and Technology, Trondheim, Norway

coline.senior@ntnu.no

Abstract. Cities are increasingly facing the consequences of climate change, it is therefore urgent to take actions to reach the targets set by the UN Sustainable Development Goals. By 2050, 70% of the world population will live in cities, engaging citizens in the sustainable transformation of the built environment is crucial. Moreover, children and youth require specific attention to secure their active participation in the process. ByMaker is a serious game developed to facilitate the participation of children and youth in sustainable urban transformation. The objective of ByMaker is to improve the knowledge about sustainability and raise awareness on the importance of making balanced decisions. While the environmental dimension is already well covered and assimilated by children and youth, the social and economic ones remain more challenging to understand. The method uses a 3D map of the concrete city, interactive elements of popular landmarks and friendly characters of local historical figures. The players are invited to experiment multiple combination of choices corresponding to different scenarios of urban development such as road and transportation, urban nature, residential buildings and public space. The impact of their decisions on the overall sustainability of their city is presented as visual feedback. Scenarios in the game focus on the realization of SDGs' ambitions and objectives. The vision is both mid-term oriented, addressing the climate urgency and long-term focused to anticipate future needs. Furthermore, ByMaker presents innovative technological solutions to play with. The game was tested in three classes in primary schools in Trondheim, Norway. The feedback guided the further development and improvements such as better visualization, interaction features and simplified scenario descriptions. By playing with ByMaker, children succeeded to learn, experiment, and create their sustainable city.

1. Introduction

The future is now. The "future generations" that the Brundtland report referred to in 1989 are already here. As cities are increasingly facing the consequences of climate change, it has become urgent to take actions to reach the targets set by the United Nations' Sustainable Development Goals. The 2023 Norwegian Youth report showed that young people place "rising prices", "war, instability, and threats on democracies" and "climate and environment" respectively at the three first places of their biggest fears [1]. This is a shift from the previous years where "climate and environment" was always placed at the top. This demonstrates a bigger emphasis on topics related to social and economic dimensions.

At the international strategic level, the IPCC has worked with development scenarios to depict a projected picture of our common future resulting in five "Shared Socioeconomic Pathways". In practice, an increasing number of municipalities and governmental organizations have adopted a similar approach

at the local level, working with midterm development scenarios to guide concrete decisions regarding urban development (e.g. EU Urban Agenda; ADEME Transitions 2050). By 2050, 70% of the world population will be living in cities, engaging citizens in the sustainable transformation of the built environment is therefore crucial [2]. Moreover, children and youth will be the ones to face the long-term consequences of the decisions made by today's adults. The active participation of children and youth is enshrined in the Norwegian Planning and Building Act and all municipalities are legally obliged to facilitate their participation in any planning proposal, regardless of whether it be carried by public or private actors [3]. Gamification of processes is one way the public authorities have explored to engage younger publics in the co-creation of urban spaces, a the most institutionalized example is the UN habitat program "Block by Block" using Minecraft for participatory design [4]. The category "games for education" constitutes the biggest bulk of so-called "serious games" applications, with documented benefits for improving learning outcomes [5]. Although games are widely used for participation and education only a few examples are found to fulfill both purposes [6].

In this context, this paper aims to investigate the following research question: *How can serious games be used to improve children's understanding of and participation in sustainable urban development?*

2. Theoretical Framework

2.1. Public participation in Smart cities

Cities are home to over half of the world population and are increasingly facing the consequences of climate change. It has become urgent to take actions to reach the targets set by the United Nations' Sustainable Development Goals. In this context, smart cities are becoming the norm in terms of development models, with municipalities investing in technologies supporting public services delivery, overall sustainability performance with the goal of improving citizens' quality of life [7]. The governance dimension of smart cities emphasizes the need for collaboration between all stakeholders and engaging citizens in sustainable urban transformation. Public participation is defined as the processes by which citizens can take part in decision-making [8]. Most if not all scientific literature on participation refers to Arnstein's ladder of participation (1969) to define the degree to which citizens can actually participate in planning, ranging from "nonparticipation" (lowest) and "tokenism" (medium) to "citizen control" (highest).

In terms of the methods used in participatory planning, conventional methods requiring face-to-face interactions such as workshops, community forums or public hearings, have an outreach limited to certain demographics of the population [9], [10]. The demographics falling short of this opportunity to participate were defined by Arnstein (1969) as the "have nots". More recently, scholars have proposed innovative ways to engage underrepresented groups in participatory planning using ICT and ultimately improve social sustainability for better livable cities [6], [9], [11], [12].

Scientific literature points out to the fact that citizens cannot effectively participate unless they understand the language being used and in turn, their contribution will not be taken into consideration by planners if it only serves private interests rather than collective ones [13], [14]. This calls for a need to alleviate the goals of participatory processes to serve the community at large and contribute to improving the overall sustainability of the city [15]. In order to make an effective contribution in the planning process, citizens need to have an understanding of the big picture and the long-term vision for the development of their city [16]. This implies juggling with complex matters and concepts that are often confined to experts or highly educated citizens, thereby excluding a large portion of the population from entering the discussion and reaching consensus [17]. In traditional participatory methods such as citizen panels, participants are randomly selected and invited to contribute to a specific aspect of a project or a plan. The municipal planners will invite experts to present important aspects of predetermined themes that should frame the discussions and their contribution to the project (e.g. impact on biodiversity, real estate and property laws, urban planning strategy, anthropology). This knowledge transfer operates in a magistral way, often in the form of a lecture given to citizens. Addressing groups

that fall out of the "privileged" categories such as children for example, requires planners to find alternative ways for communicating complex matters.

2.2. Serious games for learning

In 2020, Norway implemented a new curriculum in schools nationwide (over 600.000 pupils in primary schools in Norway in 2020), putting more emphasis on sustainability related topics. While the environmental dimension is already well covered and assimilated by children and youth, the social and economic ones remain more challenging to understand. The benefits of games and serious games are that they allow learners to experience situations and engage in learning activities that are otherwise impossible or difficult to implement and experience in the real world [18]. In addition, authors argue that games should take place in an environment where children spend most of their time since that is where most of the learning takes place [19]. There is evidence that the use of games supports the development of skills such as strategic thinking, planning, communication, collaboration, group decision-making, and negotiation skills [20]. Games in education can also bring difficult-to-understand abstract concepts closer to students and could facilitate the understanding of several scientific concepts [21]. However, despite the plethora of games and serious games available for sustainability education and those geared towards participatory urban planning, only a few examples are found to serve both purposes.

Zyda (2005) compares ordinary computer games to serious games and describes computer games as a finished product consisting of art, software, and a story. According to the author's definition, the addition of *pedagogy* (i.e., educational, or instructional activities) is essential to make a game serious, however, the entertainment component must come first, and pedagogy must be subordinate to the story. The comparison of serious games with computer games as described by Zyda is shown in Figure 1.

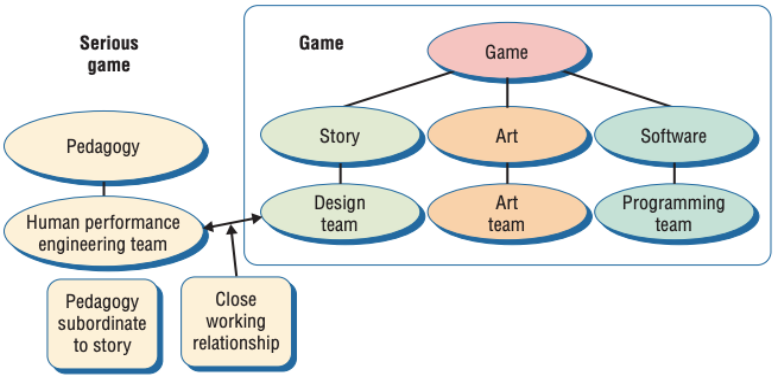


Figure 1. Comparing computer games to serious games according to Zyda (2005).

A common problem is the appearing contradiction between the terms "serious" and "game" and not everyone agrees that "fun" is an important factor when it comes to serious games, especially when considering their role in education. Games should primarily be fun and then encourage learning with elements that contribute to player engagement in a game such as motivational goals, rules that provide structure, and gameplay that leads to emotional involvement (Prensky 2001). The term *Digital natives* was first used by Marc Prensky (2001), referring to a generation who are "native speakers" of the digital language of computers, video games, and the Internet. The author points out the problem our current education sector is facing in which teachers are often *Digital immigrants* and speak a language from a pre-digital age that does not address the digital natives appropriately. A possible solution would therefore be not to invent new teaching methods from scratch, but rather to use and adapt the tools that have previously been proven as useful, e.g., developing computer games that can be used for learning.

All formal education should not necessarily be turned into a game, but there should be a reflection on how to address the "*digital native speakers*" represented by a generation of students who were raised

on computer games and expect the same kinds of interactive experiences from their educational media [19].

While entertainment games provide a "rich experience" that satisfies hardcore gamers, it is more essential for serious games that the model or simulation used can solve a specific problem [24]. In addition, learning elements should be at the core when developing serious games and the preliminary assumption should be well founded so that the simulation delivers the correct and relevant kinds of skills [24]. Entertainment games, allow players to focus on the fun parts and use different techniques to simplify the simulation processes. Serious games are supposed to respond to the conscious decision of the players, rather than to chance. Hence, randomness may be inappropriate when developing serious games.

When designing User Experience (UX) for children, it is important to consider how their behavior and perceptions differ from those of adults when using a User Interface (UI). These are summarized in Table 4 below.

Table 1. Differences in behavior between children and adults when using a user interface (adapted from Sherwin and Nielson (2019)).

	Children	**Adults**
Goal in visiting websites	Entertainment	Getting things done, communication and community
Exploratory behavior	Like to try many options	Stick to the main path
Real-life metaphors	Very helpful for pre-readers	Often distracting or too clunky for online UI
Physical limitations	Slow typists Poor mouse control	None (unless they have disabilities)
Animation and sound	Liked	Usually disliked
Advertising and promotion	Cannot distinguish from real content	Ads avoided; promotions viewed sceptically
Disclosing private information	Usually aware of issues: hesitant to enter information	Often recklessly willing to give out personal information
Age-targeted design	Crucial, with very precise distinctions between age groups	Unimportant for most sites

When designing a user interface for children it is therefore important to consider that their main goal when using an interface is entertainment so the interface should include animations and encourage exploration.

2.3. Designing a serious using the LEAGUE Framework for game-based learning

To design a game concept, we used the LEAGUE Toolkit (**L**earning, **E**nvironment, **A**ffective-cognitive reactions, **G**ame factors, **U**sability, **U**s**E**r) [26], which includes characteristics to define when developing the area of Game-based Learning (GBL).

The following points make the core dimensions identified by Tahir and Wang (2020) in the LEAGUE Framework research, each of them representing one specific aspect of GBL:

- *Learning* (Decide the learning domain of the game),
- *Environment* (Decide the technological environment for the game),
- *Reaction* (Decide the reactions you would like to generate through the game),
- *Game* (Decide the game genre),
- *Usability* (Decide the usability goal of the game),
- *User* (Decide the target players of the game)

3. Method

This study uses the Design science research (DSR) method, which is particularly well-suited for action innovation research in the context of academic-industry partnerships. Following this method, the researcher seeks to develop an artifact to solve a problem [27]. DSR addresses wicked problems, to which experts and practitioners do not have workable answers [28], [29]. DSR focuses on real problems to help understanding the gaps between the theoretical academic research and the practical field and to change existing situations into preferred ones [30], [31]. The work presented in this article involves both research and implementation using a design science approach in an iterative process based on learning from previous phases to inform the next one.

This method is chosen to address the challenge of engaging children by designing a game as an artifact to improve sustainability knowledge for decision-making in urban development. It is one of the commonly used ICT research methods for Education research in terms of ongoing and detailed measurement, monitoring and evaluation of the efficacy of the approach to integrate technology into teaching and learning [28]. Its value lies in possibility of being implemented in "real-world" conditions (ibid), which in this case means by incorporating learning in ongoing participatory processes. This contributes to addressing the shortcomings identified in the public participation literature (i.e., the lack of common language in participatory processes).

DSR methdodology follows six "activities" as defined by Peffers et al. (2007). It describes a process to design artifacts to solve identified problems, to make research contributions, to evaluate the designs, and to communicate the results to appropriate audiences (Figure 2).

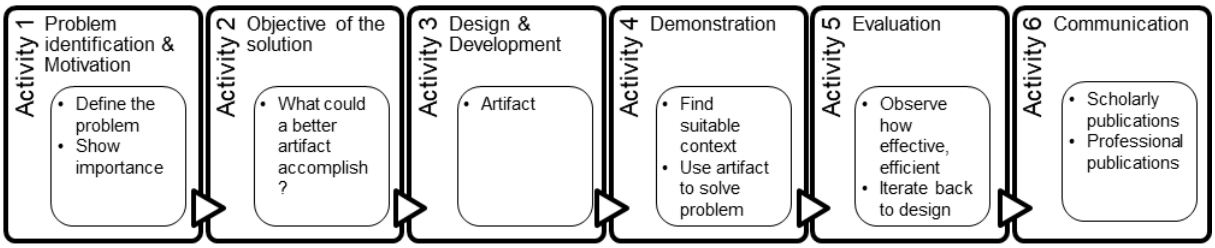


Figure 2. Activities of the Design Science Research Methodology (adapted from Peffers et al., 2007).

The purpose of each activity is listed below [32]:

Activity 1: Problem identification and motivation. Define the specific research problem and justify the value of a solution.

Activity 2: Define the objectives for a solution. Infer the objectives of a solution from the problem definition and knowledge of what is possible and feasible. The LEAGUE framework was used at this stage to frame the objectives of a prototype for game-based learning.

Activity 3: Design and development. Create the artifact. Conceptually, a design research artifact can be any designed object in which a research contribution is embedded in the design. The LEAGUE Framework was operationalized at this stage, defining each component of the game.

Activity 4: Demonstration. Demonstrate the use of the artifact to solve one or more instances of the problem. This could involve its use in experimentation, simulation, case study, proof, or other appropriate activity. This was done by supervised user testing sessions in real environment (i.e., with pupils in classrooms).

Activity 5: Evaluation. Observe and measure how well the artifact supports a solution to the problem. This activity involves comparing the objectives of a solution to actual observed results from use of the artifact in the demonstration. This was done by combining observations in the room and results from a post-test questionnaire.

Activity 6. Communication. Communicate the problem and its importance, the artifact, its utility and novelty, the rigor of its design, and its effectiveness to researchers and other relevant audiences such as practicing professionals, when appropriate.

4. Results

In the following section, activities 2 to 5 of the DSR Method are presented. Activity 1 was presented in the Introduction and Theoretical framework chapters.

4.1. Define the objectives of the solution

The LEAGUE Framework for Game-based learning was used to develop the concept of the game. The characteristics of the game are described below:

Table 2. Characteristics of the game according following the LEAGUE Framework.

LEAGUE Dimensions	ByMaker
Learning	Smart city (Sustainable city)
Environment	Web game (using Unity and WebGL), supported on desktop computers and mobile devices
Reaction	Cognitive and Behavioral
Game	Simulation
Usability	Ease of use and Efficiency
User	Children (ages 10 to 12), parents, and teachers

4.2. Design and Development of the Artifact-Game prototype "ByMaker"

The artifact designed in this study is a game prototype called "ByMaker" (City Maker in Norwegian). This following section describes how the virtual environment was developed and the gameplay designed.

4.2.1. Designing the virtual environment and gameplay

The 3D maps of the city of Trondheim were provided by the municipality and directly integrated into the Unity game engine, the game was then hosted online on the itch.io platform.

When playing the game, the players are invited to experiment multiple combination of choices corresponding to different scenarios of urban development such as road and transportation, urban nature, residential buildings, and public space. As shown in Figure 3, the impact of their decisions on the overall sustainability of their city is presented live in the form of visual feedback in the bottom left corner.

Figure 3. ByMaker game environment.

In addition to the 3D map of the city, 3D models were designed in Blender, each of them representing development scenarios in each category of urban planning "Road and Transportation", "Residential buildings", "Public square" and "Urban Nature". For each of the development scenario, a small "i" button is available to obtain more information about its concrete implication for the overall sustainability of the city.

Figure 4. Example of scenario in the category "Public square"

Friendly characters were designed to represent the sustainability pillars (i.e., Social, Environmental and Economic), each of them having three "moods" reflecting how each scenario affected them (Figure 5). The character representing the social dimension was designed after the founder of the city, Olav Tryggvason whose statue stands on Trondheim's main square.

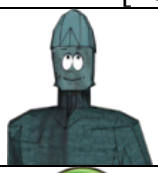
	Sad [0, 10]	Neutral [10, 15]	Happy [16, 20]
Social score			
Environmental score			
Economic score			

Figure 5. Friendly characters designed for representing sustainability pillars

4.2.2. Sustainability scoring system

Each scenario in the game is allocated a sustainability score corresponding to its impact on the overall sustainability of the city. We used the United 4 Smart Sustainable Cities' "Collection Methodology for Key Performance Indicators for Smart Sustainable Cities" [33]. This methodology provides municipalities with criteria for assessing the smartness and sustainability of a city. It is used by most of the municipalities in Norway including Trondheim, where this study was conducted. For each KPI, we used a simplified scoring system of -1 (negative impact), 0 (neutral impact) and 1 (positive impact) to assess each scenario accordingly.

4.3. Demonstration-Game prototype "ByMaker"

The game was tested during supervised sessions in three different classes of 22 to 29 pupils aged between 8 and 12 years old. For each session, three researchers participated by coming to the pupils' usual classroom and with their teacher present in the room. The session lasted for 45 minutes, including a short introduction to sustainable urban development, a live survey using Mentimeter to assess the pupils' pre-existing knowledge and assumptions regarding sustainability, 15 minutes of free gaming and a collective round up to go through the scenario combinations, a post-survey on Mentimeter, a questionnaire on paper to collect information regarding the user experience and a design activity for co-creation (Figure 6). Mentimeter is an audience response system that allows participants to anonymously answer questions and vote on polls with the results being displayed live on the screen, thereby allowing the presenter to follow-up and adapt the presentation to the level of knowledge the audience [34], [35]. The collected data can also be saved for later analysis. To measure the children's acquired knowledge after playing the game we designed the post-survey containing the same question as the pre-survey. The results can thereby be compared to determine if the children's knowledge and understanding have increased.

Figure 6. User testing session.

The paper questionnaire was focused on the user experience and motivation using Likert-scale based questions (Figure 7). In addition, a question was asked about whether playing on a map of their own city brought added value.

Exciting		Boring
Easy to play		Difficult to play
Fun		Serious
Colorful		Dull
Clean		Messy
Fast enough		Too slow

Figure 7. Example of parameters evaluated in the UX questionnaire.

The Design activity was conducted to invite players to co-create new ideas that they would like to see implemented in the game and their associated sustainability score.

4.4. Evaluation- Game prototype "ByMaker"

The evaluation of the game prototype was conducted post-event, reporting the collected data from Mentimeter, the UX paper questionnaire.

4.4.1. Learning outcomes

We measured learning outcomes by comparing the pupils' answers before and after playing the game. The most significant result relates to the question "What is the most important aspect for a sustainable city?" (Figure 8). Pupils could only select one answer between "Economic", "Social" and "All 3 are important". For sessions 1 and 3, the share of "All 3 are important" increased after playing the game. Similarly, in these sessions, the social dimension also obtained more votes after playing the game. However, session 2 saw a decrease in the "All 3 are important" and no votes were put towards the social dimension.

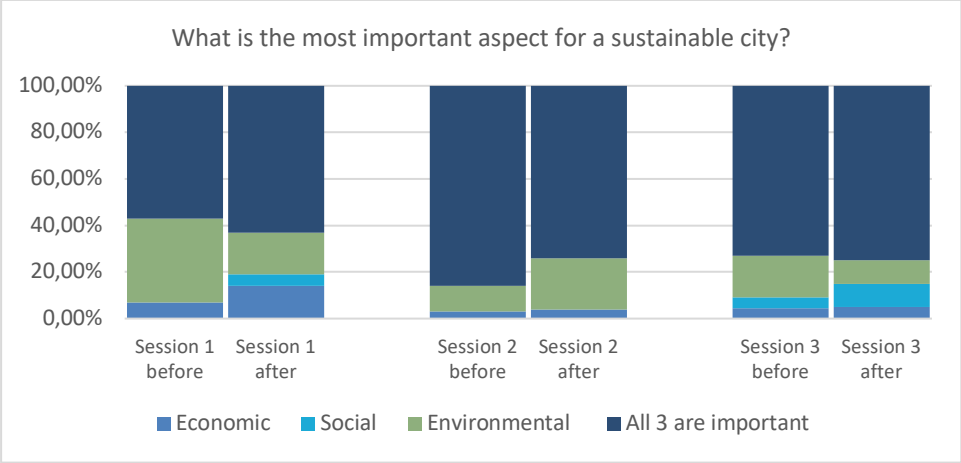


Figure 8. Results of the Mentimeter survey before and after playing with ByMaker

4.4.2. User Experience and Motivation

Results from the paper questionnaire are divided in two categories, one related to the user experience and one related to their motivation to learn by playing the game. The values presented in Figure 9 are average values for the parameters measured in each category. In all three sessions the average values for user experience and motivation score above median. This reflects a certain level of satisfaction from the pupils. The highest values are found in session 3 which might be explained by a greater engagement of the teacher in the classroom who had prepared the pupils in advance and actively helped the researchers to supervise the session.

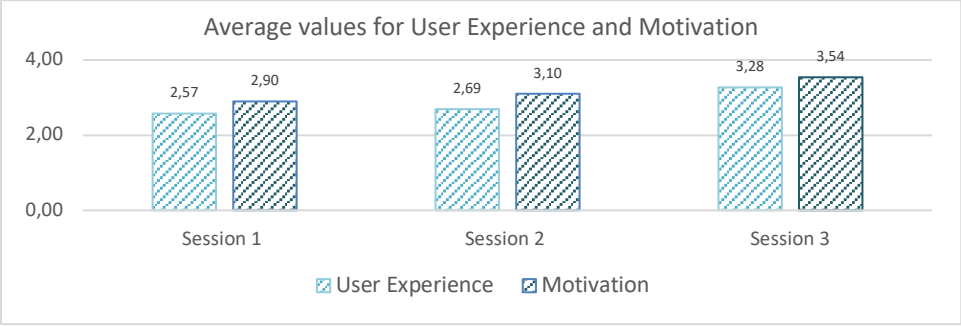


Figure 9. Results of the paper questionnaire

5. Discussion & Conclusion

By following the steps of the Design Science Research Methodology, we were able to design a serious game prototype that could increase pupils' understanding of sustainable urban development. The LEAGUE framework for game-based learning proved to be beneficial for framing the concept and defining the objectives of the artifact both from a technical perspective but also from a pedagogic perspective. Session 3 was the only one in which the teacher had prepared the pupils in advance, introducing the activity and the researchers' team prior to their visit. The teacher also mentioned that she would use this as a kickstarter for a learning cycle on sustainability in general. The pupils were therefore more responsive and engaged when playing the game. This is reflected in the results of session 3, where all values are superior to those of session 1 and 2. In addition, the researchers observed that pupils in session 2 were struggling to focus, due to a dissipated group that distracted the rest of the class. This is of course a usual phenomenon in a class and should be accounted for in later tests.
The artifact proved to be suited to find a common language between researchers and children, which constitutes a first step in securing meaningful contribution in future public participation process.

6. Acknowledgement
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