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A SMART CITY DISTRICT SIMULATOR FOR DEVELOPING FUNCTIONAL PROTOTYPES FOR ENVIRONMENTALLY SENSITIVE SERVICES

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ABSTRACT

Cities have to increasingly consider topics such as climate change and digitalization. Ideally, the digital transformation should support becoming more climate-friendly. New digital services are being developed and made available to citizens. However, it is often difficult to test ideas for new services from both a technical and a user-centric perspective. Reasons for this are, among others, that existing technical infrastructures provide a complex environment where deployment is often time-consuming. Furthermore, certain qualities such as performance or data protection have to be ensured, which is something a prototypical solution might not be able to offer. We are developing digital solutions for a climate-neutral smart city district, and one of our main challenges is that the area is still under construction and no technical infrastructure exists yet. Therefore, we developed a mock environment for a digital ecosystem in which we can easily test new ideas and early service prototypes. In this publication, we share our experiences on how we used this environment in a hackathon event and provide results from the participants who used our smart city district simulator. We provide three concrete examples of different implementations and discuss how our technical solution supports the development of new digital solutions and how it might also be a solution for other cities. As we would also like to apply the technical environment in other contexts, we then describe one concrete use case in the area of heavy rain and elaborate what this means regarding further development of our simulator and the technical infrastructure.

KEYWORDS

Smart City, Digital Ecosystem, Simulation, Digital Services, Hackathon, Experiences

1. INTRODUCTION

The digital transformation is everywhere. It influences people's everyday life just as it does companies or municipalities. New business models and services are emerging. Cities have not been exempt from this development in recent years and are increasingly offering digital services (Neirotti et al., 2014).

In addition to the digital transformation, other topics are often also relevant for cities, such as sustainability or climate change. Specifically, cities have to deal with aspects such as mobility, energy, or heat, and develop new solutions (Lea, 2017). Digital transformation can provide support here.

In the project EnStadt:Pfaff, we are developing a climate-neutral smart city district. Here, too, one question is how digitalization can help support climate-friendly behavior on the part of citizens and companies. For example, we developed a game that presents new mobility concepts in an interesting way and shows the player how the implementation of such solutions is received by citizens. Another example we developed is an app in the field of energy called Fish ´n Tipps, where a fish avatar gives the user energy-saving tips. The tips from the app can either be contributed by other users, or alternatively generated by the app itself by incorporating different data sources that are part of the smart city district ecosystem. For example, the user may be given a tip to use a rental bike for an upcoming appointment if the app has information about the availability of bikes at the nearby bike rental station, data about the current weather, and the user's appointment calendar (Elberzhager et al., 2021).

The last example already shows how important the networking of services and the use of data are in a digital ecosystem of this kind if real added value is to be provided to the user. A number of questions then immediately arise, for example regarding data protection, data usage control, technical feasibility, or business models.

Our initial plan was to develop a digital smart city platform to meet the needs of future inhabitants. However, due to the district still being under construction and the lack of concrete apartments or stores, implementing the digital ecosystem is not possible yet. Furthermore, the project faces the challenge of not having access to real users, making it difficult to identify their needs and requirements for digital solutions. As a result, the focus has shifted to developing and evaluating concept ideas. The goal now is to make the topic tangible for citizens, generate interest, and encourage participation through various formats such as apps, learning games, videos, prototypes, and hackathons. One of our central questions is how to develop and evaluate concept ideas within the context of a digital smart city platform.

Before implementing a solution, it is important to examine the concept idea in more detail to determine its feasibility and alignment with goals. This involves evaluating technical feasibility and gaining technical insights and knowledge as early as possible. Additionally, concept ideas should be assessed for their effectiveness, taking into consideration aspects such as need, benefit, and acceptance. This ensures that the right solutions are developed before investing time and effort in their implementation. To obtain feedback from citizens early on, ideas should be made tangible, for example by using prototypes. Functional prototypes are particularly suitable as they provide technical insights as well. Hence, the central question is how to efficiently develop and evaluate functional prototypes in the context of a digital platform.

In the context of a digital platform, there are several options for creating functional prototypes. One approach is to use the actual target platform to implement the prototype. Another option is to create individual mockups that simulate platform functions without connecting to other systems at all. A third option is to use a simplified platform with reduced complexity. In the case of hackathons, the last option is particularly suitable as the target platform would be too complex, and creating individual mockups would be costly. For this reason, we created a so-called “mock platform”.

The mock platform provides basic data and services and organizes networking and communication between solutions (Elberzhager et al., 2021). While implementing the mock platform, we intentionally neglected requirements and qualities such as data protection or high performance, but in return we got a technically simple way to create functional prototypes and evaluate them fast. Prototypes can dock onto this technical platform, use it, and thus make early concept ideas easier and faster to grasp. As a result, concept ideas can be presented earlier, understood more easily, and evaluated more accurately through feedback.

However, what is not sufficiently supported by the mock platform itself is the exploration and testing of prototypes of environmentally sensitive services. For this purpose, we developed a smart city district simulator (Ajdari et al., 2022). With this, we are able to simulate different aspects and thus get more accurate feedback on the effectiveness and impact of the new digital services we want to test.

Our aim is to present our technical environment in which early digital prototypes can be tested. This opens up a discussion on where such a solution may be helpful and what kinds of solutions can be tested, i.e., how mature the environment is. First and foremost, we used the technical environment in hackathon events. Results from the latest hackathon in 2022 are presented and discussed in this paper, parts of which were first published at CSC 2023 (Neuschwander et al., 2023). Based on these experiences, we further derived scenarios in which our mock platform and the corresponding technical components could be applied in the future.

In this paper, we first provide an overview of related work. Then we present a compact overview of the basic operation of the simulator, and how it has evolved. In Section 4, we show how we used the simulator in the context of a hackathon event and give some examples of the different solutions developed in that environment and their added value. We discuss the results and the experiences made. Afterwards, we present one detailed scenario systematically to show where we see further potential for our technical environment, and give a summary of its use in further areas. Finally, we close with an outlook on future work in Section 6.

2. RELATED WORK

Various simulation environments for smart cities exist already. Dong et al. (2021) showed a smart city simulator that is built on the open-source platforms “OpenStreetMap” and “Simulation of Urban Mobility”. It focuses on the simulation of uncertainty, i.e., the simulation of “real” city events in the domains of transportation, emission, and energy.

Esposte et al. (2019) describe a simulation component for the “InterSCity Platform”, a microservice-based middleware for the development of smart city applications, which uses models of real-world scenarios to generate simulated workloads to test the capabilities of smart city platforms. Hence, Esposte et al. aim at generating testing scenarios for smart city platforms, rather than scenarios for triggering creative thinking processes in order to come up with solution ideas, e.g., at a hackathon event.

In the context of smart cities, the term “simulation” is used ambiguously. Li et al. (2020) describes “real-time urban simulation” as an approach for analyzing and interpreting the continuous flow of real-time city data to make accurate predictions of the future. Digital Twins are another common concept to support planning and decision-making in smart cities, where data and simulation models are used to test the effectiveness of concreate measures before implementation (Vessali et al., 2022). Digital Twins in a smart city context also refer to the use of 3D models to simulate the impact of urban planning decisions on traffic and the overall skyline of a city (White et al., 2021). This use of the term “simulation” is different from ours as it refers to an existing smart city platform in production compared to the smart city simulator and mock platform we propose for modeling future use cases in smart city environments prior to production.

Lom and Pribyl (2021) approach the modeling of smart city scenarios from a Systems Theory perspective. Intelligent smart city agents model real-world behavior of citizens and infrastructure within a smart city (e.g., electric vehicles and charging stations) to simulate various scenarios and support the design of smart city applications. Their approach tries to simulate real-world behavior as close to reality as possible, hence requires a thorough understanding of the system participants and their expected behavior. We focus on best-case scenarios to stimulate the creation of novel smart city solutions rather than exact real-world representations.

3. SMART CITY DISTRICT SIMULATOR

3.1 Concept and Implementation of the Smart City District Simulator

The smart city district simulator provides a virtual city district that can be used for simple simulations and quick prototyping of environmentally sensitive services in the field of smart cities (Ajdari et al., 2022). The original concept and implementation comprise, among others, software-based sensors as well as controllable virtual actuators linked to a virtual world. Those components can serve as substitutes for their real-world counterparts and facilitate prototyping of smart city solutions (e.g., environmentally sensitive services) on a small scale. In combination with its visualization component, the smart city district simulator can support various stakeholders, such as the general public, future citizens, and developers, in exploring and empathizing with the presented scenarios and prototypical solutions. People can experience what it might be like to live in a smart city district and provide early feedback, which can be used to further improve the concepts and shape the future city district.

Figure 1 gives an overview of the realization of our smart city district simulator (a.k.a. “Gameboard”). The idea is to substitute the whole real city district with a simplified virtual one and to provide an easy-to-use environment that supports exploring new ideas. The state of the virtual world (i.e., the world state) is managed in a central place called “Gameboard Backend”. We differentiate between “fields” representing the map of the virtual world (i.e., the layout of the future city district) and “tokens” representing entities in the virtual world (e.g., pedestrians, vehicles, streetlights, and so on). It is possible to add scripted play to the virtual world by adding actor scripts to the “Gameboard Simulation” component, to add sensors to the virtual world by implementing software-based sensors (e.g., as part of the “Gameboard Sensor Server” component), and to add controllable virtual actuators by implementing corresponding control components that provide an API and introduce the related state changes to the world state. Environmentally sensitive services can be created that can consume the sensor data and reach out to the control components to manipulate elements in the world (e.g., turning a streetlight on or off). The "EcoLight" service is a simple example service that consumes pedestrian detection events from pedestrian detection sensors and controls streetlights in the city district in a demand-actuated way by using the corresponding example control component "Streetlight Control". Last but not least, there is the "Gameboard Frontend" component, which continuously renders and visualizes the current world state in a way that is suitable for human observers so they can actually observe what is happening in the virtual world.

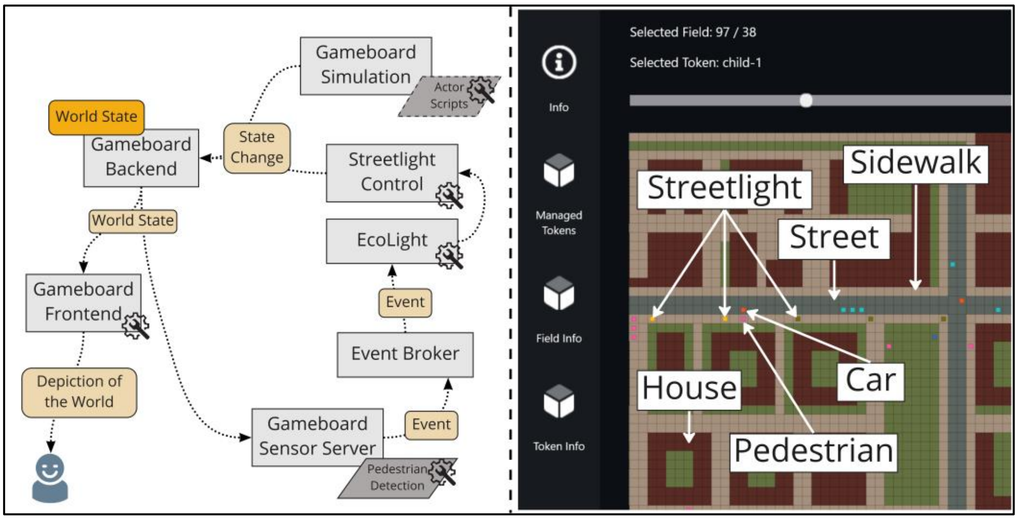

Figure 1. Smart city district simulator: implemented components, intended modification points marked using wrench icon (left), and gameboard frontend user interface (right)

Sensors provide their data as events using an event broker in order to have loose coupling with the services. For the same reason, control components should provide an API so that they can be accessed by the services without leaking too much implementation details or introducing tight coupling with the Gameboard Backend. By having such abstractions, the underlying world implementation (i.e., whether the environmentally sensitive service is connected to the virtual city district or the real city district) is hidden / encapsulated and ideally does not leak into the implementation of the prototypical environmentally sensitive services. This ensures that the prototyped innovations can be transferred to and implemented in the real world using real sensors and actuators.

3.2 Advancement of Smart City District Simulator Implementation

We further improved the implementation of the smart city district simulator and its integration with our mock platform environment. The goal was to make the simulator more inviting and easier to use, especially for people who are unfamiliar with it. This section provides an overview of the main advancements.

3.2.1 Additional Actors Representing Example Inhabitants

In an early version of the simulation, there was only one single actor representing a pedestrian walking along a sidewalk. We added eleven additional actors representing example inhabitants of the future city district performing different activities (e.g., taking a walk in the park, driving a car, riding a bike). This is intended to make the virtual city district appear livelier and more natural. The goal is to help users empathize better with the shown scenarios and thus allow us to develop promising concept ideas. These ideas should not only improve the lives of people living in this urban district, but also lead to more climate-friendly and sustainable behavior.

3.2.2 Remote Control

The early version of the Gameboard Frontend was only able to display the current state of the world. To introduce changes to the world, one had to technically issue a request to a backend service. To facilitate getting to know the smart city district simulator and the testing of sensors and prototypes, we introduced remote-control functionality. Remote control is a special form of a control component that provides a user interface and allows creating and controlling tokens at runtime. In our implementation, we support moving a token one step in the direction of choice. We integrated the relevant user interface elements into the Gameboard Frontend for better usability. Using this feature, users can influence the virtual world more easily by introducing new entities and moving them around with just a few clicks. For example, they can create a token representing an inhabitant or a vehicle and navigate it through the virtual city district. Given there are sensors in place, the remote-controlled tokens will trigger them. The remote-control feature thus helps to stimulate the virtual world, possibly resulting in reactions that can then be observed. One obvious purpose for using remote control is stepping in and out of a sensor's range to test whether that specific sensor or an environmentally sensitive service behaves as expected. The feature can also be used for demonstration purposes, e.g., when presenting an idea or a prototype to a broader audience. Remote control complements the actor engine and its actor scripts.

3.2.3 Connecting Existing Services with the Smart City District Simulator

Initially, our simulator was quite isolated from the other services that already existed in the mock platform environment. The pedestrian detection sensors did already publish their sensor data to the event broker and any other service could easily subscribe to them. However, only our new environmentally sensitive example service EcoLight actually consumed them. We decided to connect some existing services to the new smart city district simulator in order to explore and demonstrate the new opportunities enabled by the simulator.

There is another component available called "smart home simulation". This component provides a 3D rendition of a smart home with sensors and actuators that can interact through a user interface. Furthermore, it is connected to the event broker and also publishes process state changes related to smart home devices. Simulating and displaying presence information is one feature available in smart home simulations. In the past, we controlled presence by clicking a button on the user interface and flipping a Boolean flag accordingly. We identified the opportunity to provide the sensor data for the presence of selected smart home instances using our smart city district simulator and sensors that observe the fields corresponding to buildings. Whenever a token representing a human enters or leaves the boundaries of such a building in the virtual world, the presence information sensed by the sensors is published to the event broker as a smart home event. To do so, we use a modified version of the pedestrian detection sensor that publishes the detection information as smart home presence according to our event specification for smart home information. These events are consumed by smart home simulations and other services subscribing to them. The smart city district simulator and its new sensors generate smart home presence information based on the virtual world. One can observe that the presence displayed in a smart home simulation depends on the presence of tokens in the virtual world of our smart city district simulator. With this mechanism, even more applications can be included and more complex application scenarios can be created.

3.2.4 Inspection View with References to Complementary Resources

The early version of the Gameboard Frontend could display plain information about the properties of the fields and tokens. Now that there is connectivity to other elements in the mock platform environment, we decided to enrich the inspection view for fields and tokens by providing support for displaying references pointing to other resources related to that entity. For example, for a token representing an inhabitant, we can add a reference to that person's user profile; and for a field of the type house, we can add a reference to the corresponding smart home instance in the smart home simulation. This facilitates the exploration of related information and services.

4. EXPERIENCES FROM THE PARTICIPANTS USING THE SMART CITY DISTRICT SIMULATOR IN A HACKATHON EVENT

4.1 Hackathon Setting and Onboarding Activities

We used the simulator at a hackathon in November 2022. A hackathon is a 24-hour coding event in which the participants are assigned a task that they have to solve in small teams. During this time, they have to create a solution concept and present a programmed prototype at the end. At our event, 35 people participated in nine teams at one location. They were mainly students and young professionals with a computer science or other technical background. Their task was: "How can information from and about public spaces help citizens behave more sustainably?" It had to be implemented digitally. The main goal of the hackathon event was to get digital solution prototypes from the teams. However, we were also very interested in learning to what extent the smart city district simulator is able to support the participants; i.e., we used the hackathon event to gain as much feedback as possible from the participants regarding our simulator. We were especially interested in how quickly they would be able to use our simulator, and how well it would work from a technical and usability perspective.

As an additional incentive for the participants, prize money was offered to the three best teams, which were determined by a jury. The jury judged the idea as well as the technical implementation. The criteria for the assessment were: novelty, added value for the city district, technical maturity and design, and use of the mock platform environment.

To enable the participants to use the smart city district simulator as well as the rest of the mock platform environment, we relied on a multimodal learning concept. This consisted of a variety of different materials, such as documentation, source code examples, explanatory videos on YouTube, and a playful approach. To familiarize the hackathon participants with our mock platform, its services, and the smart city district simulator, we developed Pfaffhack Adventure. Pfaffhack Adventure is a web-based exit game based on the open-source solution "WorkAdventure" (2023). To solve the game, the players need to interact with the mock platform environment in a specific way to retrieve four-digit secret codes that can be used to unlock subsequent stages of the game towards the exit. The secret codes were integrated into the implementation of several mock platform components (similar to an Easter egg), and there are clues in Pfaffhack Adventure on how to trigger them. In this way, the participants were able to get to know and explore our mock platform environment, the services, and the smart city district simulator in a playful manner.

Regarding the smart city district simulator, we implemented the secret code in a modified pedestrian detection sensor that observes a specific spot in the virtual smart city district and publishes the code as part of the detection event once a token is detected entering that location. To solve the riddle, players have to subscribe to the pedestrian detection events at the event broker (to see the code) and must introduce or navigate a token to the right location in the virtual smart city district (to trigger the sensor, e.g., by using the remote-control feature in the Gameboard Frontend).

On the day of the event, we gave a talk to introduce and further explain our mock platform environment including the smart city district simulator. We explained the general concepts behind it and how the provided material, e.g., the source code of several of our software components, could be used by the teams.

In order to be able to gain experiences from the participants, the majority of the authors of this paper were deeply involved in the hackathon event. During the whole event, we continuously talked to the teams, helped them during the implementation, and listened carefully during the standup meetings. At the end of the event, we performed a feedback session where all participants were able to reflect on the event itself, but also on the technical environment and the simulator.

4.2 Hackathon Project Ideas and Prototypes Using the Smart City District Simulator

The participants developed several ideas and prototypes. Three out of nine teams used our smart city district simulator to realize their prototypes, as their ideas for digital prototypes were well supported by the simulator. This section presents the results of these three teams.

4.2.1 Team 1 (a.k.a. "bike punks")

The team "bike punks" brought up the issue that there are many cars on the road and there is not enough space for cyclists and pedestrians. In Germany, pedestrians are required to use the sidewalk and cyclists are required to use the road unless there is a bicycle lane or signs allowing them to share the sidewalk with pedestrians. In everyday life, cyclists often have to share the road with motorists. One can observe that many car drivers do not show appropriate consideration for cyclists (i.e., tailgating and overtaking without a safety distance). Under these circumstances, riding a bike can become quite dangerous and fewer people are willing to use a bicycle to get around. This impedes certain forms of more sustainable and climate-friendly mobility.

The team's suggested approach was to adjust the usage of the roads to the needs of the people and to encourage sustainable and climate-friendly mobility. Roads are not necessarily primarily for cars; there are other road users whose needs should be considered, too. For example, by introducing speed limits or other usage restrictions (e.g., assigning lanes to cyclists and/or pedestrians), one can address their needs, enable safe participation in traffic, and encourage climate-friendliness in everyday life.

The smart solution envisioned and prototyped by the team monitors the utilization of roads and dynamically adapts their usage restrictions. For example, given a multilane road and just a few cyclists and pedestrians on the road, it is likely that they can share a lane. If the number of cyclists increases, one of the car lanes might become a bicycle lane and a speed limit might be introduced for the other car lanes. In the case of roads with only two lanes, the whole road might temporarily become closed to cars. Once the number of cyclists decreases, the introduced restrictions could be reversed. Such a solution could provide priority to road users worth protecting, without banning cars in general. Having such a smart solution that provides space and safety for weaker road users will make the city district more inviting for them and might motivate even more people to use bicycles to get around. In more general terms, the idea of the team is about dynamically adjusting the use of public spaces using smart technologies to support the common good.

4.2.2 Team 2 (a.k.a. "GridScorer")

The team "GridScorer" brought up the issue of decision-making in the area of spatial planning. Decisions regarding spatial planning may sometimes appear to be arbitrary and hard to comprehend for the general public. According to the team, even the decision makers themselves (i.e., local representatives) sometimes do not feel informed well enough to decide and are therefore sometimes not confident in their own decisions. There is no adequate data basis to support informed decision-making in the field of spatial planning.

The team suggested creating such a data basis to support decision-making in spatial planning by gathering relevant information (e.g., regarding utilization/visitor numbers) about numerous places in the city district. The collected information could be made publicly available and analyzed by the municipal administration to find out what parts of the city district need attention. Having such a data basis would provide decision makers with reliable data supporting informed and comprehensible argumentation and decision-making. By continually gathering and using this data to continuously improve the city district, city officials could ensure that it remains welcoming to all and supports them in living a more sustainable and climate-friendly lifestyle.

The smart solution envisioned and prototyped by the team monitors the spatially resolved utilization/visitor numbers of the public space over time. The data is recorded and stored to form a reliable data basis. Additionally, there is functionality to visualize aggregated data as a heat map.

4.2.3 Team 3 (a.k.a. "hacking.exe")

The team "hacking.exe" brought up the idea of providing the city district with a sustainable workout area, giving the community a place to exercise and improve their well-being. They got inspired by existing solutions in other areas and adapted the concept to the city district. Kinetic tiles mounted on the floor would generate electricity when stepping on them. The electricity generated in this way could be used to power nearby electronic devices (e.g., lighting). Every step would be a contribution supporting the environment.

The team suggested installing such kinetic tiles in the city district as part of a running or walking track to harvest and utilize the energy to power or charge nearby devices (e.g., lighting, sensors, e-bikes). According to the team, people from all over the city would come to the track and get stress relief while generating energy.

The smart solution envisioned and prototyped by the team captures/records the athletes' steps and the amount of energy produced. This information makes the individual contribution/impact perceivable for the individual athletes and the overall impact for the general public. Additionally, their solution contains elements of gamification; one can compete with friends, climb the leaderboard, complete challenges, reach daily goals (either personal or community goals), and/or earn rewards. This can support/motivate people to do more sports and lead to a healthier lifestyle. In addition, doing sports to generate electricity can teach more conscious use of electricity as a resource and reduce energy waste. People will experience what it takes to produce a portion of electricity and may wonder how electricity is generated through means other than such climate-friendly ones.

4.3 Observations Regarding the Use of the Smart City District Simulator

Team 1 ("bike punks") used the smart city district simulator to prototype their solution. They copied our Gameboard Simulation component and created their own actor scripts for a group of cyclists riding their bicycles in the virtual city district. Then they copied our Gameboard Sensor Server component and implemented sensors to observe several road sections, checking how they are currently used and capturing the number of pedestrians, cars, bicycles, and other types of road users currently using the road sections. Depending on how the observed road section is currently used and based on a set of example rules, the sensor modifies a newly introduced property of the gameboard fields that represent the road section to reflect the currently assigned usage restriction. Additionally, the sensed utilization information is published to the event broker as an event.

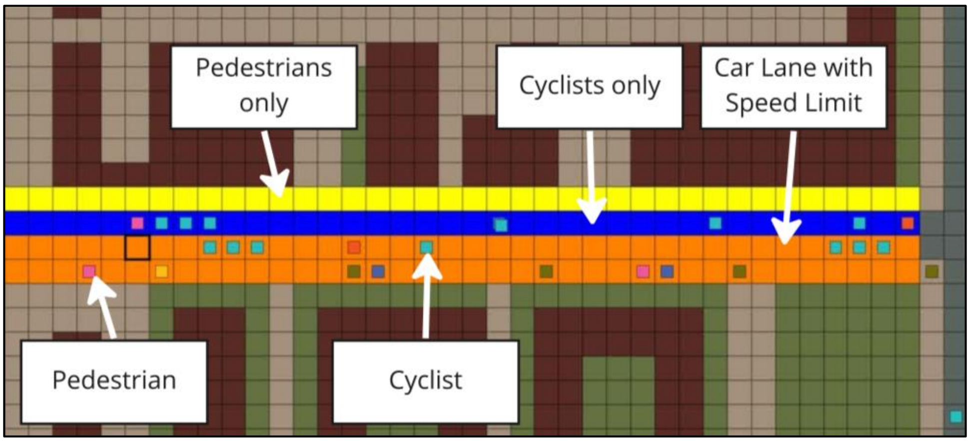

Figure 2. Visualization of the prototype of the team 'bike punks' with additional explanatory annotations

Our existing visualization component does not consider the newly introduced property when rendering the fields and therefore they are all rendered the same (i.e., the currently assigned usage restriction is not visualized). To display the usage restrictions assigned to the road, the team copied and modified the source code of our Gameboard Frontend component to consider the newly introduced property and draw the fields in different colors depending on the currently assigned usage restriction. Using their modified version of the Gameboard Frontend, it is possible to observe the change in road section usage restrictions each time cyclists enter or leave this road section. When pitching their solution to the audience, the team used a screenshot of their visualization component to explain their vision. Figure 2 shows an extract of that screenshot with additional explanatory annotations. As there are currently several cyclists on the road, the prototypical smart solution assigned individual lanes to pedestrians and cyclists. Furthermore, a speed limit is applied to the remaining car lanes. The entities using the road do not comply with the usage restrictions. For example, there are pedestrians and cyclists using the car lane.

Team 2 (“GridScorer”) also used the smart city district simulator to prototype their solution. They copied our Gameboard Sensor Server component and implemented a sensor that detects tokens representing persons within the sensor range. Then they divided the virtual city district into 110 cells (each consisting of 10x10 fields) to be monitored regarding their utilization. Each cell is observed by one sensor instance that publishes the sensor data to the event broker. Then they implemented a dedicated service to process the sensor data. There is a score for each cell that is incremented every time a detection event for that cell is received. The scores are persisted using the storage service provided by the mock platform environment. To visualize the scores, the team implemented a user interface. The user interface fetches the stored cell scores from the storage service and displays them in a grid. The cells are colored differently to make it easier for users to differentiate between cells with higher and lower scores (similar to a heat map). The team did not implement any actor scripts to introduce any additional entities or behavior to the virtual world; instead, they observed the already present actors (see section 3.2.1) and what the other teams added during the hackathon event. When pitching their solution to the audience, the team used a screenshot of the gameboard and a screenshot of their own user interface with the colored cells bearing the scores. They arranged the latter as a half-transparent layer on top of the first one so the audience could recognize the match.

Team 3 (“hacking.exe”) implemented a mobile application for athletes with real-time tracking of their steps and the energy generated by them. There are also numerous mocked screens for the gamification aspects of their solution (e.g., leaderboard, challenges, daily goals). The team used the smart city district simulator to provide their application with step detection events from the virtual world. To do so, they copied our Gameboard Sensor Server component and implemented a sensor that reports a step detection event every time a token representing a person steps on the spot observed by the sensor. They instantiated several sensors that observe spots along a track in the virtual city district. The events are published to the event broker, which is part of our mock platform. They connected their mobile application to the mock platform to consume the detection events as they are generated. To generate the events, the team used the remote-control feature of our Gameboard Frontend component (see section 3.2.2). They navigated a token representing an athlete along the track, triggering the sensors to generate the step detection events that are consumed and further processed by their prototypical mobile application. In the application, they count the step detection events and display real-time statistics (e.g., total electricity produced).

4.4 Interpretation and Discussion of the Observations

Two of the teams used the smart city district simulator and its virtual world solely as a source for data to trigger their solution with input data from sensors (teams “GridScorer” and “hacking.exe”). They stimulated their prototype using the virtual world and the reaction is only observable within their prototypical application. However, the solution by the “bike punks” team additionally impacted the virtual world (i.e., the reaction of their smart service in the underlying world) and can therefore be easily observed and empathized with by human observers. The team was the only one that closed the loop by using the smart city district simulator as a source for sensor data as well as a sink for actuator instructions. Having the stimulus and the reaction visualized in the virtual world helps to empathize with the situation and the causalities of the presented solution. None of the teams used the smart city district simulator solely as a sink just to visualize the impact of their solution on the world (without having their solution triggered by the virtual city district). No team used the simulator solely to tell a story or present a certain scenario without implementing a prototype.

The “bike punks” team implemented multiple concerns in their sensor: the sensor logic to determine the utilization of the road section, the business logic to decide what usage restrictions to apply to the road section, and the logic to apply the new restrictions by updating properties in the Gameboard Backend. They could have separated these parts intro three building blocks: sensor, environmentally sensitive service, and control unit. Implementing everything as part of the sensor introduces high coupling and leaks implementation details of the smart city district simulator to the environmentally sensitive service. When we noticed this, we were unsure whether the team did not understand our concept regarding the different types of components and their separation or whether there were other reasons for this. We talked to the team, and it turned out that they were aware of our concepts and had tried to save effort by implementing it as a single software component. As one of the simulator’s main purposes is to facilitate quick prototyping, we consider it valid to take shortcuts and simplify as much as possible. The teams created prototypes that should support presenting and testing their ideas to get early feedback; therefore, it should be totally fine to do such hacks and simplifications. This is more or less the same as we do with our mock platform; we intentionally neglect qualities that would be required for production-ready solutions in order to speed up and simplify test implementations. One just needs to keep in mind that this comes with a tradeoff. In the case of “bike punks”, the team did not detail the parts related to the actuators. Technically, they just flipped some bits in the world state. In the real, physical world, this is not possible. The team did not explore what it means technically to apply certain usage restrictions to the roads and how actuators could be integrated. Nevertheless, the audience was still able to get the idea and discuss it.

We also observed that the “bike punks” team used four street lanes for their scenario, while there were actually only two street lanes available in the city district layout that we used for the simulator. In order to get two additional lanes, they repurposed the sidewalks next to the street and applied usage restrictions to them, too. In the real world, it would make no sense to assign a sidewalk for use by cars. On the one hand, this could be an indicator that the suggested solution might not be applicable to the future city district and therefore the solution should be changed to suit the city district. On the other hand, however, having a fixed layout could be too limiting. There could be interesting solutions for other city districts or alternative design options for the present city district. Nevertheless, our city district layout was a limiting factor for them, and they made the best of it; and most importantly, people were still able to understand their general idea. Providing the participants with their own copies of the Gameboard Backend with an easy possibility to configure custom layouts might give them more freedom to choose a layout that supports their prototype ideally.

Another observation that is related to providing the teams with a single shared instance of the Gameboard Backend is that the scripted play provided by us and possibly by other teams will interfere with the solutions of the teams. As a result, we were able to observe that there is a pedestrian walking on a lane that is assigned to cars in the “bike punks” team’s scenario, as the pedestrian’s path is scripted using hardcoded coordinates that match the original sidewalk. On the one hand, it could be interesting to have all the teams share one world and explore how they can interact and influence each other. It might be possible to connect and combine different solutions that could complement each other. On the other hand, there could also be great potential in being able to provide each team with their own instance, if needed, in order to enable them to arrange their scenario without interference from elements already present or introduced by others without coordination.

None of the teams used the simulator to show a live demonstration of their prototype during the pitches. We do not know the exact reasons, but the short amount of time available during the final presentations might have prevented them from using the simulator.

4.5 Opportunities Provided by the Smart City District Simulator

To summarize, the presented smart city district simulator offers three key opportunities. First, the simulator allows for early evaluations and insights, enabling ideas and approaches to be assessed before any production-ready code is written. This also allows for early feedback from stakeholders, thus helping to identify and address potential issues. Second, the simulator provides a cost-effective test environment by simulating the smart city district, allowing solutions to be developed and tested before investing in expensive hardware. This lowers the barrier for developing new solutions. Finally, the simulator offers a low-threshold opportunity for the active participation of non-experts, such as citizens. Civic participation and co-creation (i.e., involving different stakeholders in the development process) can be a way to enhance the acceptance and benefits of the resulting solutions. Additionally, it helps developers to better understand the needs of the target group and incorporate them into the product.

5. SCENARIOS FOR USING THE SMART CITY DISTRICT SIMULATOR

During the last three years, we developed the smart city district simulator. There were several development steps and different versions were applied, especially in hackathon events such as the one described in this article. The technical environment was further developed based on feedback from the participants, respectively from our own ideas. As we are approaching the end of the research project in which the district simulator was developed, we are thinking about how we can apply the simulator in other projects and contexts. In order to systematically gain an overview of the possibilities we see in this regard, we will provide one detailed example in the following and then give some further ideas in a short summary at the end of this section.

5.1 Using the Smart City District Simulator with Data Platforms

5.1.1 Motivation

Data platforms are used more and more frequently by municipalities and cities. Usually, simple use cases where such data platforms are considered are implemented first to check their technical feasibility, their acceptance by users, and the benefits of digital solutions. Examples include a) trash cans equipped with sensors so that the routing of the garbage collection trucks can be optimized, and b) parking lot occupancy so that drivers can easily find an empty parking spot. Based on our experiences, it often happens that more data is collected than what is really needed for the intended use cases. One reason for this extra data to be collected may be its potential usefulness in future new uses cases that may result in further benefits. The decision makers in municipalities understand that data is being collected, but it is often difficult for them to imagine further uses of such data. As long as there is no concrete use case and the benefits are not clear, it is often not possible to invest money in the development of such digital services.

Therefore, it is usually necessary to have very concrete use cases to show how data can be used and what the benefit of such implemented use cases is. If decision makers see some kind of visualization, understand the processes shown in the use case and the benefits in the real world, they are more likely to agree to the development of such digital services. The simulator environment is suited to demonstrate different use cases, and the effort for this implementation is rather low compared to a real digital service.

5.1.2 Example Use Case “Rain”

One concrete example use case can be found in the area of weather, especially regarding heavy rain. Smart cities may use digital services that utilize data in different scenarios. Two concrete scenario examples to be derived are “monitoring heavy rain events” and “controlling heavy rain events”.

In the first scenario, “monitoring heavy rain events”, sensors could be placed in certain locations to measure whether it is raining, the intensity of the rain, the water level and whether there is any flooding, or the water flow rate in the sewers. Weather data could be helpful to derive forecasts. A simulation could show such a heavy weather event and the consequences, and foster discussions about where such sensors might be relevant. The benefits of early warnings or concrete actions in case such an event is forecast could be shown. Besides focusing on heavy rain events, rain events in general could also be tracked.

In the second scenario, “controlling heavy rain events”, actuators could be used in the sewers to control where the water flows in order to prevent or reduce flooding. Signals could warn pedestrians, cyclists, drivers, and other road users.

Assuming that such scenarios are implemented, further connected scenarios could be considered, such as “analyzing the risk of forest fires”. If it is analyzed how often and in which quantity rain is falling, it can be calculated how great the risk of forest fires is. This could result in more adequate warnings for people and better and earlier preparation for fighting potential forest fires. Another example scenario that builds on top of the first and second would be the “watering of green spaces”. The moisture content of public green spaces in a city could be analyzed to determine whether it is necessary to water them. To do this, sensors would be needed in such places. A map could show the moisture content and motivate citizens to support the city, for example by watering plants in their neighborhood.

Implementing such scenarios in our gameboard would make them easier to understand for municipal decision makers and enable a broader audience to be included. The benefits of installing sensors and actuators across a city could be estimated better, and the implementation of such services could be based on an initial prototype developed and tested using our mock platform environment.

5.1.3 Technical Issues

The current version of the simulator does not support water events. However, it is reasonable to further develop it to be able to show the scenarios described above. To do so, the following extensions need to be considered. First, weather information needs to be shown, especially rain. This has to be generalized to a certain extent, as obviously not every raindrop needs to be implemented. However, it is necessary to simulate different levels of rain in order to distinguish the intensity of the rainfall. Second, flooding information needs to be shown, i.e., areas where water is not directly flowing into the sewers, but is accumulating. Here, it may also make sense to present different levels in order to show how much water is present in flooded areas. This could also be visualized with different colors to show the concrete danger. Third, the user interface needs to be improved to show the scenarios in a way that is easier to understand for people with a limited technical background. And fourth, a data platform used for storing historical sensor and weather data needs to be connected to the simulator environment to display such data. For this, the standard interfaces available in urban data platforms should be sufficient for sending data from the data platform to the simulator and enabling the simulator to request specific data.

In order to realize these new data entries, we already have, e.g., properties for the fields and global environment variables for the virtual world. These can be used to place rain information. We also have sensors to sense the tokens, so one can analogously implement sensors to detect changes in the rain-related parts of the virtual world. The events can be reported to the broker and consumed by the data platform or other services.

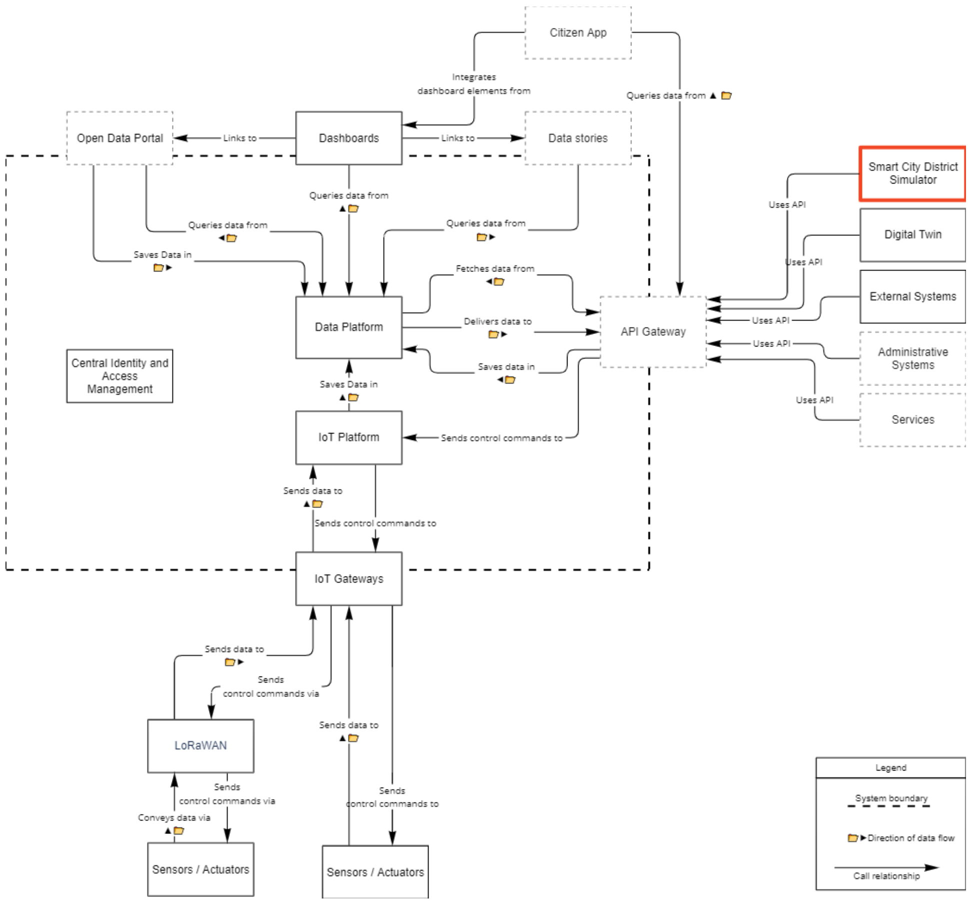

Figure 3. Conceptual architecture of the integration of the smart city district simulator into a typical data platform

Figure 3 provides a technical view on the complete landscape in the given scenario. The center is the data platform, which operates certain services and uses, e.g., dashboard components providing and visualizing certain information, communicates with sensors and actuators via gateways, and also communicates with additional systems such as our smart city district simulator.

5.1.4 Questions to Be Answered with the Rain Use Case

Such a simulated use case would support answering further concrete questions. The simulator is intended to support the development of smart city use cases, but is a presentation in the simulator sufficient to illustrate the use case and make it understandable for as many stakeholders as possible? Currently, the focus is rather on functionality and less on the user interface. However, especially stakeholders with only a limited technical background might not easily understand what they see in the simulator. How can the use case and its scenarios be implemented as simply as possible in a prototypical manner? And, on the other hand: What technical details can already be derived for a future real implementation of the use case? What conclusions can be drawn for the technology to be selected? A more general question beyond the rain use case is the feasibility of graphical programming of the algorithms of the use case visualized in the simulator in order to quickly realize and change a prototype. This is interesting from both a technical and a usability perspective, as the aim is to enable a broader audience to interact with the simulator and get a better understanding of the use case.

5.2 Reflection on the Future Use of the Smart City District Simulator

The elaborated use case regarding the topic of heavy rain is currently being implemented by us. We expect concrete input in the future by decision makers of cities when we use the use case to demonstrate what a data platform can offer and what benefits cities can get when implementing these or other scenarios. Other use cases may capture mobility topics, such as parking space optimization or charging stations to support e-mobility, construction site planning, fire station placement, or weather monitoring to facilitate extreme heat warnings or monitor air quality.

We also expect to develop an improved version of our simulator environment in terms of the power of the simulator, as a concrete new use case is being implemented with further functionality, and the technical environment extends with the data platform. Technical questions may arise during these activities, but we are convinced that in general, the implementation will be possible.

6. CONCLUSION AND OUTLOOK

In this paper, we presented our current smart city district simulator, which we developed to enable us to test new digital services for a climate-neutral smart city district. One main feature is that new digital prototypes can be evaluated quickly without worrying about certain qualities such as performance, security, or privacy, which are needed in digital ecosystems in actual operation.

In order to check what is useful and feasible and can be supported when developing digital solutions, we used the smart city district simulator in a hackathon event. We provided a variety of background material for the participants so that they could prepare for the event. During the event, nine teams developed different digital solutions. Three teams used the smart city district simulator and were presented in this paper. It turned out that the teams were able to use the technical components of the simulator and could integrate their solutions into our mock environment. Based on our observations during the hackathon event and the participants' feedback, we can conclude that it was helpful for the teams that we provided them with the source code of our components. They could easily copy and adjust it to their needs to implement their own scenario.

While we applied the simulator environment in the context of a smart city district, which is reflected by a virtual map of the district in the simulator, we believe that this might not be the only context in the future. Therefore, we presented one additional use case that is also becoming more and more relevant for cities, namely heavy rain events. We derived concrete scenarios that could be implemented to make it easier for municipal decision makers to understand and assess the possible benefits of a real implementation in their cities. This also makes it clearer for the general public how digitalization can support climate topics. Additional adaptations may make it possible to use the simulator even better in different environments to get early feedback during the development of digital prototypes.

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