USING A SMART CITY DISTRICT SIMULATOR TO TEST NEW DIGITAL SERVICES

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ABSTRACT

Cities have become more and more digital in recent years. They have developed various digital services that they provide to their 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 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 report on how we used this environment in a hackathon event and provide experiences from the participants that used our smart city district simulator. We provide examples of the solutions and discuss how our technical solution supported the development of new digital solutions and how it might also be a solution for other cities.

KEYWORDS

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

1. INTRODUCTION

The digital transformation is everywhere. It influences everyday life just as it does companies or municipalities. New business models and services are emerging. Cities have not been exempted 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 an ecosystem of this kind if real added value is to be gained for the user. A number of questions then immediately arise, for example regarding data protection, data usage control, technical feasibility, and business models.

In our project situation, we must deal with the following challenge: The district is currently under construction, i.e., there are no concrete apartments or stores yet, and the area is still largely unoccupied. This means that the digital ecosystem cannot be implemented yet. However, we certainly need to develop digital solutions and test prototypes and initial services. For this reason, we created a mock environment, or more precisely a mock platform, where we can get early feedback on digital services in a simple way [Elberzhager et al., 2021]. In doing so, we neglect requirements and qualities such as data protection or high performance, but in return we get a technically simple way to deploy services and evaluate them.

To analyze in more detail how such services behave, we recently 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 is helpful and what kinds of solutions can be tested, i.e., how mature the environment is.

In this paper, we first present a compact overview of the basic operation of the simulator, and how it has evolved. Then 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, and finally give an outlook on future work.

2. SMART CITY DISTRICT SIMULATOR

2.1 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.

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.

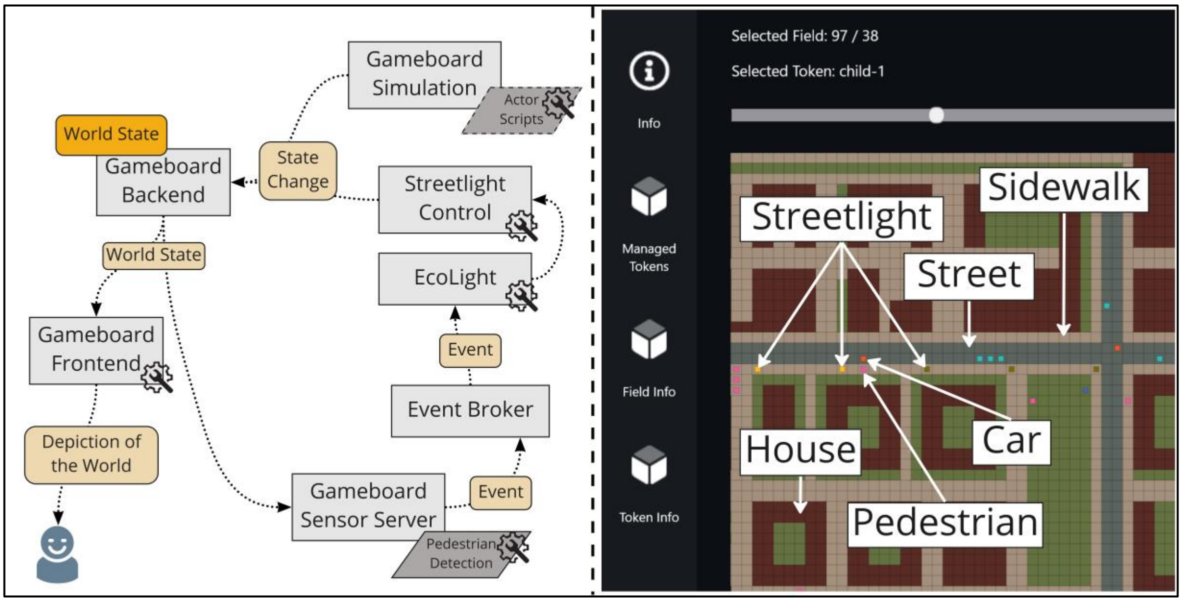

Figure 1. Smart city district simulator: implemented components, intended modification points marked using wrench icon (left) and gameboard frontend user interface (right)

2.2 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 two main advancements.

2.2.1 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.

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

3.1 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. Of course, 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” [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, all 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 the event itself, but also the technical environment and the simulator.

3.2 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.

3.2.1 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 as long as there is no 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 is to adjust the usage of the roads to the needs of the people and to encourage sustainable and climate-friendly mobility. The road is 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.

3.2.2 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 well enough informed 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., about the utilization/visitor numbers) of 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.

3.2.3 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 32Tmore 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.

3.3 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 as an event to the event broker.

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.

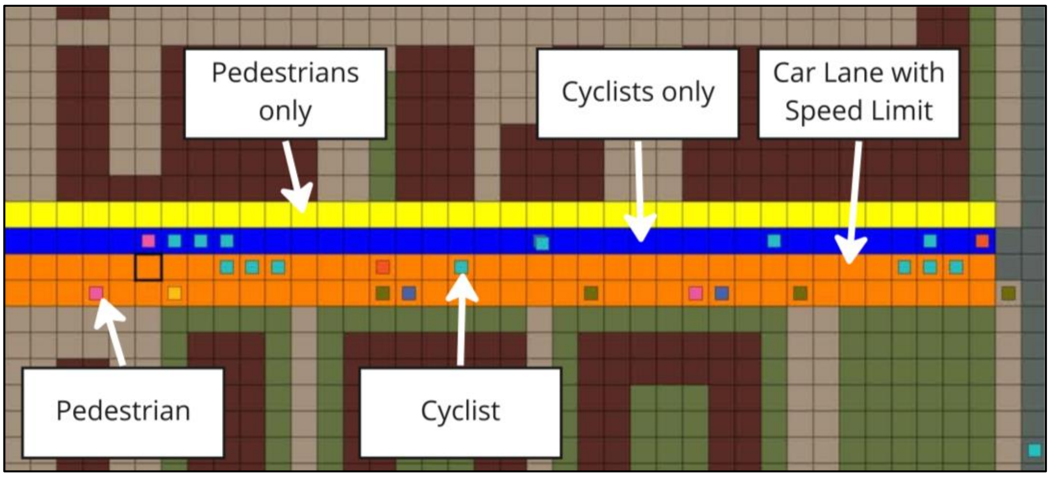

Figure 2. Visualization of the prototype of the team ‘bike punks’ with additional explanatory annotations

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 2.2.1) 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 2.2.2). 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).

3.4 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.

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. 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. CONCLUSION AND OUTLOOK

In this paper, we first presented our current smart city district simulator, which we developed to enable us to test new digital services for a 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 applied 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. Some adaptations may make it possible to use the simulator in different environments to get early feedback during the development of digital prototypes.

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