Smart City Planning

Group 8

David Rosenbusch
Juliette Hoedemakers
Justin Krooneman
Ray Pohjanheimo
Zack Wilson
Annkatrin Jung

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1. Goals and problems we aim to solve:

1.1 Introduction

City planners, or urban planners, often face problems when they carry out their work. These problems can occur after they have developed the first ideas for a neighbourhood or city. Some examples of such problems are[1]: (i) Private ownership interfering with planning of urban areas, (ii) lack of regulations and (iii) irregularity of environments.

In the case of private ownership (i), a landowner may have unrestricted right for the use of his land. With this right he might be able to build a factory in a residential area, leading to a decreased value of the properties in that neighbourhood. This can be solved by increasing information earlier in the design and building processes through clearer information visualization and simulations.

A lack of regulations can be the cause of private owners converting farmland into urban building lots. This might happen so often, that the capacity far outstretches the current and upcoming generations' needs for housing. This could lead to high-grade residential areas becoming surrounded by cheaply constructed homes.

Since these issues can easily lead to decreased land value for the surrounding areas due to, for example, pollution or traffic flow, we aim to give city planners a tool to see the effects of their designs without constructing the buildings in the real world, but rather constructing the buildings in a *virtual world*.

In addition to these problems, modern city planners and developers are becoming increasingly aware of opportunities for more sustainable development. However, to take advantage of these modern technologies, more complete information about neighborhoods and systems must be made available earlier in the design process, so that urban planners can make more informed

[1] http://www.yourarticlelibrary.com/problems/3-main-problems-faced-in-urban-planning/4695

choices. This could require specialists from different fields to work together from an early point on.

1.2 Technical Solution

To solve these problems and take advantage of these opportunities, we propose a novel software solution to visualize information about neighborhoods, cities and environments, as well as simulate those spaces. Our solution offers a virtual reality environment to enable collaborative planning of smart cities and systems. This system combines several key features:

- A multi-layered map to visualize, superimpose and manipulate data
- Visualization of various types of data (e.g. energy consumption, pollution, maintenance, population density, traffic flow)
- Real-time collaboration between stakeholders in disparate environments, including urban planners, architects, engineers, managers, property owners and clients
- Manipulation of these virtual worlds through virtual reality support

Through this system we envision two major successes. First, enabling users to see data in meaningful visualizations and simulations will help them to solve problems related to new developments by preventing adverse effects on both the environment and citizens. Secondly, it will enable the design of more circular, sustainable and adaptable cities through increasing the information available earlier in the design process. Additionally this will allow better integration of new buildings and neighborhoods into the existing infrastructure, and help bring the existing infrastructure into these new sustainable ecosystems.

2. Description of Approach

In this chapter we describe the core problem we aim to solve, which is, how to plan smart cities in an immersive, interactive, and collaborative manner? We briefly define smart cities and their benefits, and describe how to measure the key metrics for smart cities.

2.1 Smart Cities

First, defining what a Smart City embodies is necessary in order to meet matching criteria. Kontinakis and De Cunto (2015) state that a Smart Cities has these aims:

1) Improvement of quality of life
2) Better services from the city to the citizens
3) City contains the creation of competent and innovative high skilled jobs.

On a project level, the most important results would be:

- Creation of innovation and knowledge
- Better Public Transportation (PT)
- Protection of the environment
- Better education and skill building
- Cleaner Energy
- Digital Infrastructure and E-services
- Better city governance
- Creation of local enterprises
- Improvement of housing conditions
- New jobs
- Protection of natural resources

Therefore, a **smart city** can be defined as a city that efficiently:

1. Mobilizes and uses available resources (including but not limited to social and cultural capital, financial capital, natural resources, information and technology) for efficiently

improving the quality of life of its inhabitants, commuting workers and students, and other visitors **[people].**
2. Significantly improves its resource efficiency, decreasing its pressure on the environment and increasing resiliency **[planet].**
3. Builds an innovation-driven and green economy **[prosperity].**
4. Fosters a well-developed local democracy **[governance].**

A smart city **project** is a project that:

1. Has a significant impact in supporting a city to become a smart city along the four axis of sustainability mentioned above
2. Actively engages citizens and other stakeholders
3. Uses innovative approaches
4. Is integrated, combining multiple sectors

A smart city project can be executed on the scale of:

1. A single building, for instance improving the energy performance of a theatre, or...
2. A neighbourhood, for instance improving the waste collection, to the scale of...
3. A city or even a region, think of an improvement in the public transport system.

As the definitions and aims of smart cities display, there are remarkable benefits for quality of life, prosperity, and sustainability associated with smart cities. Therefore aiming to provide these benefits should be a priority in future city planning.

2.2. Key Performance Indicators

We use certain Key Performance Indicators (KPI) in order to track progress and to guide the Smart City planning. These KPI should be able to indicate differences made so that comparisons can be made and improvement is to be known.
Important is that some changes will be more prominent over time so the component of time should be taken into account.
There is no current fixed metric known, however, for the purposes of our project we used the indicators from CITYkeys, an EU co-funded project in Smart city research ("CITYKeys - Home", 2019).

2.2.1 Rationale

The reasons why KPI are necessary is to be able to:

1. Evaluate the impact of a smart city project comparing before and after situations or comparing expected impact with a reference situation. As such they can also serve to benchmark projects against each other.
2. Monitor the progress of the city as a whole towards smart city goals. The time component -“development over the years”- is important. The city indicators may be used to show to what extent overall policy goals have been reached, or are within reach. In addition city-level indicators may be used to compare cities with each other, although such a comparison should be done with care.
3. Assess how the project has contributed to the objectives at city level. This requires connecting outcomes of a project evaluation with corresponding indicators on the city level. This is still very challenging.

2.2.2 The 3Ps

KPIs can be used to evaluate the success of smart city projects and the possibility to replicate the (successful) projects in other contexts. As follows from the smart city definition, success is determined by the transition across the entire ecological footprint of urban areas, simultaneously promoting economic prosperity, social aims and resilience to climate change and other external disturbances. Over the past decennia, the concept of sustainability - split up in the triple bottom line of social sustainability **(People)**, environmental sustainability **(Planet)** and economic sustainability **(Prosperity)** - has become generally accepted in the development of indicator systems for national and regional urban development (SCOPE, 2007). The 3 Ps (people, planet, prosperity) have also gained considerable ground in company reporting (Kolk, 2004).

2.2.3 Other Indicators

The extent to which smart city projects are able to have an effect on social, environmental and economic indicators forms the core of the evaluation. However, this is not enough to determine the success of a smart city project. Success is also determined by the manner in which projects have been - or will be - realised in various contexts. The Governance of developing and implementing urban smart city projects is a determining factor for high scores in People, Planet and Prosperity indicators (Fortune and White, 2006).

Therefore we need to include a number of indicators to evaluate the importance of the city context (external factors) and quality of the development and implementation process (internal factors).

Finally, the ability of individual smart city projects to be replicated in other cities and contexts determines its ultimate effect in achieving European goals with regard to energy and CO_2 emissions. Under the Propagation category, smart city projects are evaluated to determine their potential for up-scaling and the possibilities for application in other contexts.

An overview of the framework can be seen in Figure 1.

Figure 1. Framework for Smart City

2.2.4 Chosen KPIs

Because of the time constraints of this project and in order to begin with a simplified version that maintains a clear overview, a decision to focus on “People” and “Planet” has been made. For future work, other KPIs and other elements should be added.

2.2.4.1 People

The term “People” in a KPI context, refers to sustainability of a city with long term attractiveness for the users and citizens. It has to do with the quality of living and should be livable and accessible for vulnerable inhabitants. Other aspects include education, health care, social inclusion etc.

A table with an overview of the definitions taken of all the sub themes can be seen below, there are taken from the paper “The key performance indicators (KPIs) and their impact on overall organizational performance “[1].

Health:	Improving the quality and accessibility of the public health system for everyone and encouraging a healthy lifestyle
Safety:	Lowering the rate of crime and accidents
Access to (other) services:	Providing better access for everyone to transport, amenities and affordable services in physical and virtual space
Education:	Improving accessibility and quality of education for everyone
Diversity and social cohesion:	Promoting diversity, community engagement and social cohesion to increase the sense of community.
Quality of housing and the built environment:	Encourage mixed-income areas, ensure high quality and quantity of public spaces and recreational areas, and improve the

	affordability and accessibility to good housing for everyone.

Examples for the KPIs retrieved from CITYkeys:

- % of people (apartment buildings) with access to healthcare within 500m radius
- % of people with access to nature within 500m radius
- % of people with access to public transport within 500m radius
- % of people with access to commercial amenities within 500m radius
- % of m^2 covered by publicly accessible WiFi

2.2.4.2 Planet

The term “Planet” as a KPI embodies the sustainability and aspects regarding “a cleaner city”. A cleaner city means a high biodiversity, and high resource efficiency. A smart city should also be able to adapt to changing climate (especially in the future) where problems of flooding risk and heat waves/droughts can become problematic.

Also, less consumption of fossil fuels and more focus on renewable and green energy contribute to a positive Planet KPI value in regards to Smart Cities. Lower waste generation and recycling and less air pollution also contribute to this heme.

A table with an overview of the “planet” definitions taken of all the sub themes can be seen below, there are taken from the paper “The key performance indicators (KPIs) and their impact on overall organizational performance “[1].

Energy and mitigation:	Reduce energy consumption, use waste energy and produce renewable energy
Materials, water and land:	Creating a society that treats its resources (materials, water, food and land) more efficiently and sustainably, among others by decreasing consumption and increasing

	recycling and renewable production (thereby considering ‘spill-overs’ to other resources).
Climate resilience:	Adapting to climate change by increasing the resilience of vulnerable areas/elements.
Pollution and waste:	Decreasing the emissions to the environment (in the city or elsewhere) (e.g. waste, noise and pollution to air, water and soil).
Ecosystem:	Stimulating biodiversity and nature conservation

Examples for the KPIs retrieved from CITYkeys:

- % of local renewable energy production
- % carbon dioxide emission
- % in kWh increase in local renewable energy production (renewable e
- % in kWh reduction in annual final energy consumption
- % in m3 increase in water reused
- % in tonnes self-sufficiency

3. The Application

3.1 State of the art

There are already multiple systems and software solutions in place to aid urban planning, from 3D design[2] to geographic information systems (GIS)[3]. These tools combined provide much more functionality in diverse areas than we could implement in our prototype, and we did not intend to muddy the waters further by adding yet another system that would be incompatible or in competition with others. At the same time, merely adding a VR-feature to an existing system will not enhance it any further than adding another gimmick that will soon be outdated, if not kept up-to date with the overarching system.

Instead, we aim to create an interface layer that is easy to adapt to both new and changing data structures and new interfaces.

3.2 Application Architecture

To show the potential of an approach that relies on modularity in both data structure and user interface, we decided to create a simple prototype that would feature easily exchangeable data-sources, behaviour settings, and user interfaces. Our prototype shows the potential of VR in urban planning, through the immersion, sense of space and intuitive controls, but it will not rely on it nor force the user to use a VR-headset.

3.2.1 Interface Components

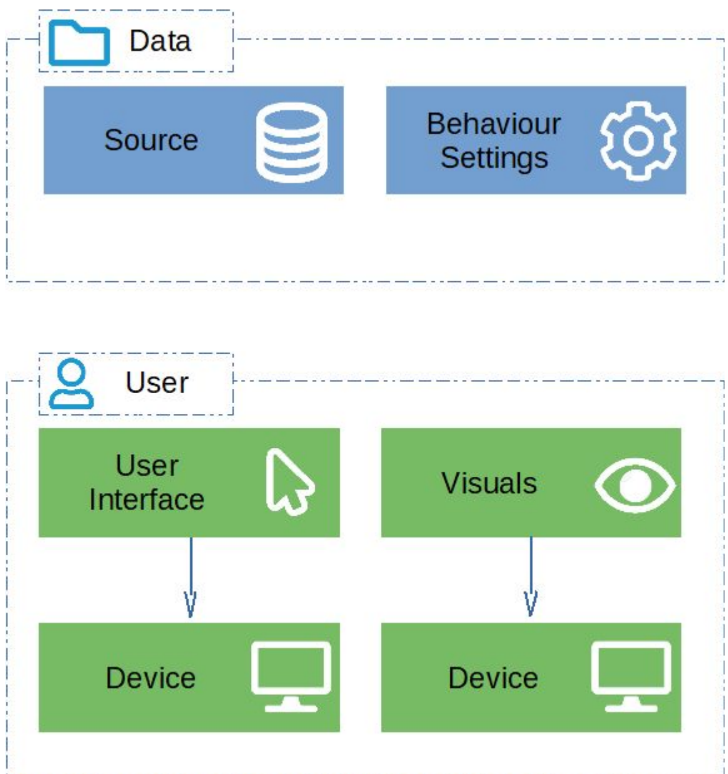
Considering the different stakeholders who work in different environments using different work computers and tablets, we knew that there would not be a one-fits-all approach. Workers on site will have different needs than planners working from an office or government officials.

It is for that reason that we decided to build a system that works across different operating systems (Linux, Windows and Mac), devices (high-end PCs, lower end laptops, tablets and phones) and interfaces (classic mouse and keyboard, touch interfaces, text-editors and VR headsets).

[2] https://www.sketchup.com/industries/urban-planning
[3] https://www.esri.com/en-us/arcgis/products/arcgis-online/overview

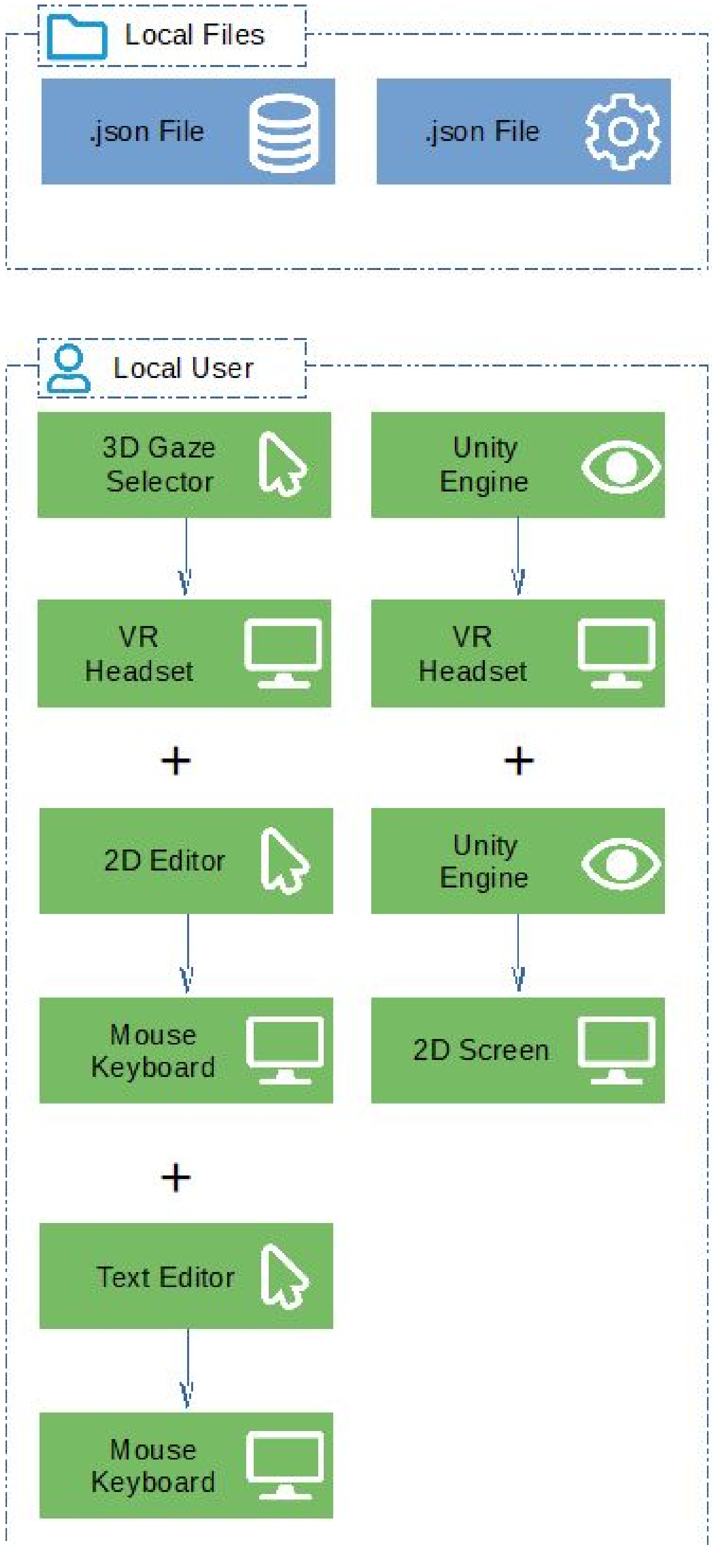
We also figured that given that our clients are probably not software developers, the application should be easy to adapt without altering and recompiling the source code. At the same time however, extending the code (to add new interfaces, data structures or visualizations) should still be easy enough for a small team or a single contractor to do. With those things in mind we decided on a modular approach in which both visualization and user interface are interchangeable.

A generic explanation of our architecture would look like the figure below. Note that all the colored boxes are easily exchangeable.



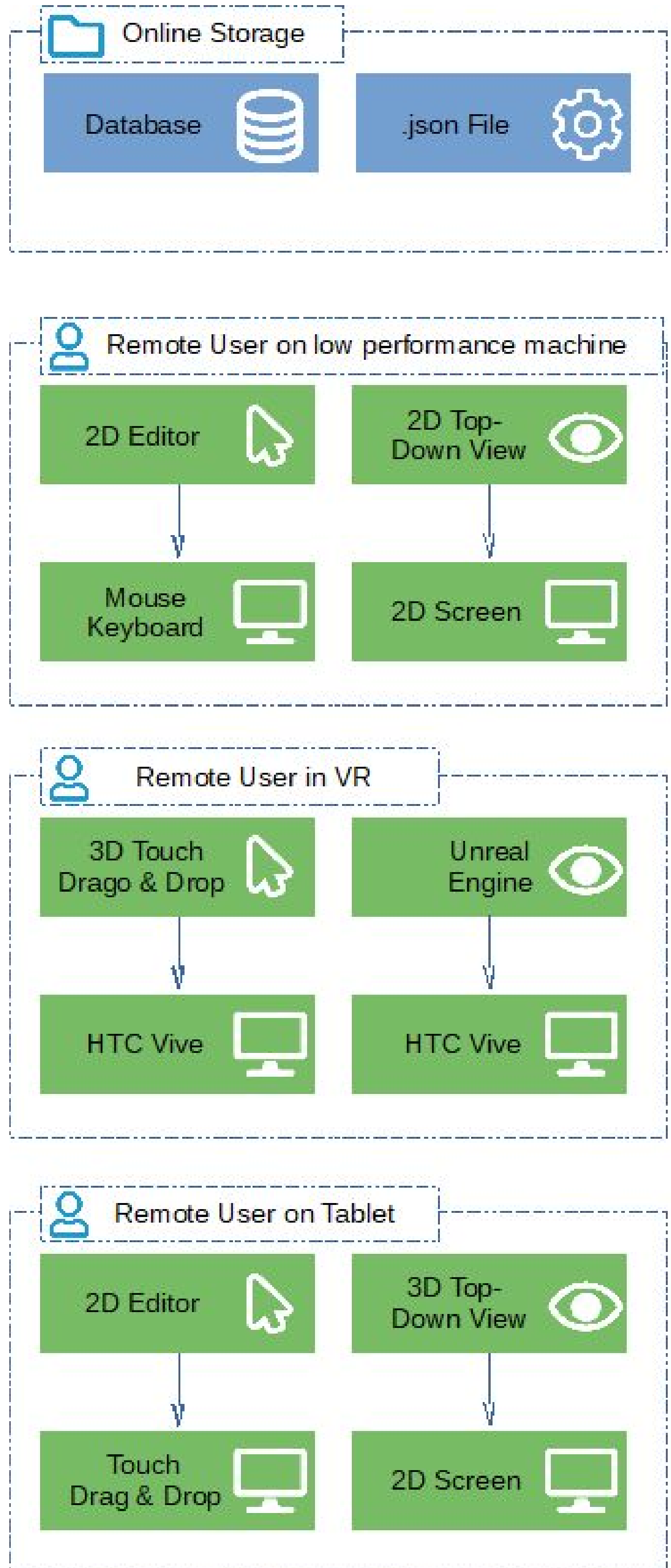
The figure below shows how our current (demo-) application is structured.

Note that we only combine multiple interfaces and visualizations in one machine due to time constraints in building the demo.



But there are, of course, many other variations of technologies and interfaces that would work under this architecture.
Once our application is fleshed out more and we spent some time implementing alternative visualizations and online-connectivity, a multi-user setup could look like the figure on the right.

A core feature that is already completely implemented is the synchronization between data and visualization. In a single local application this is naturally assumed to be the case, however as soon as multiple users interact on the same data, it must be assured that they are all seeing the same results at the same time.



3.2.2 Data Components

Our demo shows the interaction of two data components, both of which are of course simplified to allow the fast creation of the demo:

- **The city data**
  This data contains definitions for buildings (location, size, population, energy consumption), roads (location, size, direction) and the city as a whole (size, street-, building- and green spaces).

- **The application behaviour definition**
  Different users may want to highlight different aspects in a city and thus provide insights specific to their area of expertise. An environmentalist might want to point out areas with high consumption of energy, whereas an urban planner would highlight districts that need to provide more living spaces. The behaviour definition is a set of conditions that are applied to all entities within the city, each condition specifying a way to highlight any entity that fulfills it.

While we provide a multi-user environment, this only makes sense if we also provide a multi-layered map so that different stakeholders can present their perspectives to each other. Given that the city-data and behaviour definitions are synchronized for all connected users, it would take a user a few seconds to edit the current data-model (using whichever interface they choose), to jump to a different version of the same city, a whole different city altogether, or to switch out the behaviour definition, which effectively means switching the current visualization layer (for instance from an environmental to a population-centered perspective).

4. Realisation

4.1 Our Prototype

4.1.1 Current Features

We developed a first prototype which can be used by various stakeholders in disparate locations to design a sustainable city from scratch, as well as to integrate new buildings and neighborhoods into existing models. For this, stakeholders can use a virtual reality application, a 2D editor or just a simple text editor.

In the text editor, users can edit the JSON files containing the definition of the city components and the application behaviour definitions. They can see the changes in real-time in either the VR or 2D interface.

However, they can also use the VR or 2D editors to modify the city. Both show a multi-layered map with a superimposed grid. Users can move around the map and dynamically add new buildings and roads with custom metrics, as well as modify existing elements. These key metrics are further explained in section 4.3. Currently, we have implemented three types of buildings: Industrial, business, and default (residential) buildings. In the VR environment, they can use raycasting to select the desired spaces on the map or already existing buildings and roads. In the 2D editor, we implemented this functionality with a side-bar menu which allows users to add new elements at specified coordinates on the map.

After new elements have been added, the system evaluates the chosen metrics and highlights problematic buildings and areas. This classification is based on the conditions which have been defined to describe the application behaviour. For example, the system could use specific colours or animations to mark buildings with a high energy consumption, so that users can immediately see any problems the city might face.

Due to this flexible and easily customisable data representation, our prototype allows users to experiment with different city models. They can quickly modify the data in whichever editor is most convenient for them, and see the changes and their effects on the city performance in real time. This also facilitates the collaboration between multiple stakeholders, and allows them to reconcile their goals and requirements.

4.1.2 Future Steps

For the future, we would like to extend our data model and the range of elements that can be added to the city. We are currently missing several essential aspects, the main one being transportation since having good mobility and transportation infrastructure is essential for smart cities. For this, we would implement different transportation vehicles (e.g. cars, buses, trains, planes) and types of infrastructure (e.g. railroads and tramways).

Furthermore, we could also consider different types of buildings, for example buildings related to healthcare services, education or recreational activities, as well as parks or water areas.

All of these additions open up new performance indicators we can implement, so that we can give a more accurate rating of the city's sustainability and performance.

4.2 Product-Life-Cycle

As the needs for modern cities change, so will the application needed to be kept up to date. The workload that comes along with this can be minimized by making it as generic and easily extendable as possible, so that users without programming backgrounds can easily add entity types and conditions to the city.

Optimally, the core application would not need to be touched, as the modular data-models and user interfaces are modernized. It would also be worth considering publishing a simple API with which to implement plugins, modifications and extensions to the system without the need of understanding its core components.

4.3 Chosen KPIs

Our current implementation is based on some cursory research into key performance factors for cities, but the key for our project is that the flexibility inherent in the system means none of these are set in stone and can be edited or changed completely by new partners or clients. However, we chose the following key performance indicators for our demo, which are based on the indicators selected by the CITYkeys project.

- Planet
    - Total CO_2 emissions in tonnes/year
    - Renewable energy production in MWh/year
    - Total energy consumption in MWh/year

These indicators quantify the impact on the environment, and can be set as properties of each municipality in our system.

- People
    - Commercial access: Percentage of people with access to commercial amenities within 500m radius (50 grid in the application)
    - Nature access: proportion of green space per capita
    - Population density: proportion of inhabitants per grid square

These indicators quantify the living conditions of the inhabitants of the municipality. They cannot be set directly, but are rather calculated from other properties of the municipality.

We use these six performance indicators to calculate an overall score for the municipality, called the smart city index. This score is obtained by averaging the following four percentages.

- Renewable energy production / total energy consumption: If a city can produce enough energy to satisfy its own needs, it can minimise the negative impact on the environment caused by additional energy consumption.
- 1 - (CO_2 emissions per capita / global maximum CO_2 emissions per capita): During our research, we found that the goals of individual cities for reducing their CO_2 emissions vary significantly, depending on the location and population of the city. Therefore, we

compare the emissions per capita to the global maximum, which is around 20 tonnes/capita. This allows us to obtain a metric which is comparable for multiple cities.

- Commercial access
- Nature access

These metrics are scaled to range between 0 and 100%, with 100% indicating an optimal performance of the municipality.

Based on the smart city index score, we can classify the performance of each municipality into six categories:

- > 90% = excellent
- 70-89% = good
- 50-69% = adequate
- 30-49% = poor
- 10-29% = abysmal
- < 10% = nonexistent

In this way, each municipality receives an overall score based on validated key indicators, which can be used to identify strong and weak points of the city's strategy.

4.4 Final Project

For multiple people to be able to work remotely and simultaneously we decided to use GitHub for version control. Thus, running our project is merely a matter of navigating to our VR-City-Planning repository[4] and downloading the master-branch.

The root-directory contains three files...

- *.gitignore*, which is only interesting for developers and specifies which files not to include in the version control system
- *Readme.md*, which is only interesting for developers as well and contains instructions for them
- *Documentation.pdf*, which is a copy of this document

[4] https://github.com/TheRDavid/VR-City-Planning

… and the folder *Unity-City-Planning* which contains the actual software project that can be run in the Unity editor.

The unity project contains two scenes that can run out of the box (given the correct environment):

- normalScene.unity
- vrScene.unity

The normal scene is merely a 3D view of the data model, whereas the vr scene contains an actual editor. Both scenes will react to changes in the data model in real time. The unity scene themselves are very simply, as they merely need a light source and a *mainObject*, which will trigger our script to launch the system. None of the scenes we showcased during the demo were built in unity, but read from json.

To move in both scenes, use the WASD keys and SHIFT to increase your speed.

5. Recommendations

5.1 Advice for client

5.1.1 Integration

Our product employs ease of integration into current workflow with the different modality support. Further, it may easily connect (or adapt) existing data models for different projects. It quickly and efficiently combines and visualizes different data models based on different conditions.

5.1.2 Tailoring

Based on our emphasis on building a very flexible system we are essentially waiting for potential partners to request more exact, tailored versions of the system to the exact needs of different groups and stakeholders. Since our product is so flexible, tailoring it for different needs is a comparatively smooth process.

5.1.3 Robustness

The product is built on a steady foundation of modifiability and accessibility for multiple users at the same time. These factors make our product robust and scalable for small and large enterprises. In addition, our architecture enables changing the entire data models, making it a well-rounded solution for city planning.

5.1.4 Flexibility

Limited only by the imagination of the user, our product’s primary strength is its flexibility. Further functionality could easily be implemented based on the level of flexibility. This is a great opportunity for partnerships to add functionality based on the expertise of people in the construction industry.

5.1.5 Dependencies

Our product relies on JSON, which enables usage by multiple stakeholders.

6. Reflection

Before the conclusion, we will shortly reflect on the progress of our prototype, the aspects that worked out well throughout this course and the lessons learned.

6.1 Group organization

Given the large size of our group, we decided early on to strictly split tasks between sub-groups. In the very beginning, after our initial brainstorm-phase to flesh out the basic idea, we came up with two approaches to realize our demo:

1. Find an existing software that visualizes city-data (like a city building game) and adapt it to function across different devices and data configurations. If we could find an easily adaptable open-source project, this could save us a lot of time.
2. Create a simplistic application from scratch to be in full control of the application.

Since we did not know which path would lead to faster results, we split our group into two subgroups to follow both approaches for a week and then continue with the path that gave us faster results. This turned out to be the second path.

For the rest of the project we were split into two groups with rotating members, that either focussed on the VR-application or the adaptable data-sources, behaviour definitions and alternative interfaces.

6.2 (Lack of) Communication with the Client

We intended to pitch our idea to Paul W. Burghardt (paul.w.burghardt@gmail.com) to receive feedback and adjust our goals, however, after an initial exchange to organize a meeting, they stopped replying to our emails. We then decided to put more emphasis on the modularity of our approach, so as to anticipate criticisms and change requests from potential clients. The lack of guidance ultimately led us to create a solution that is geared to be changed with little effort in order to fit each individual stakeholder in a city-planning project.

6.3 Presentation Feedback

One very interesting point was raised from an audience member at the end of our demonstration, in which they pointed out that these days cities are often not designed by hand with an editor, but rather generated automatically and then evaluated. What follows from this is that instead of investing most of the time creating a city-editor, a city evaluation too is needed morel, specifically considering the aforementioned key performance factors. We are grateful for this insight at such an early stage of the project. At the same time we can leverage the adaptability of our system to shift the focus from city building to city evaluation. This would simply mean that we would invest less time in creating tools to craft a city and more into visualizing different aspects of a city.

Fortunately, our tool is just as good a fit for evaluation as it is for creation, given our idea of easily exchangeable application behaviour definitions (see 3.2.2). These could be used to put any number of visualization layers in quick succession over a generated city, or to compare the same visualization across any number of generated cities.

6.4 Lessons learned

We certainly feel that splitting the group in order to follow multiple approaches for a week to quickly get results was a good idea and more productive than arguing over which approach to follow. However, we also discovered that figuring out a new technology such as a VR headset and trying to implement a demo works a lot smoother when done in pair-programming rather than splitting the workload of that single task.

One big mistake we made that cost us multiple days of progress was that we got stuck trying to get the HTC Vive to work, instead of switching to the Oculus Rift earlier.

The Vive in the lab often failed to connect to SteamVR for hours on end, an issue that we did not manage to reliably solve and thus our progress came to a halt for half a week, as the presentation deadline was already closing in.

However, as soon as we decided to cut our losses and switch to the Rift, merely a week before the deadline for our demo, progress kicked back in. With the Rift working right out of the box, it took us less than two days to create the complete VR interface and record the footage for our demo presentation.

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[1] The key performance indicators (KPIs) and their impact on overall organizational performance

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