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Conference Paper

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Publication date:
2022-05-30

Permanent link:
https://doi.org/10.3929/ethz-b-000557135

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Originally published in:
International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XLIII-B5-2022, https://doi.org/10.5194/isprs-Archives-XLIII-B5-2022-51-2022

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DEVELOPMENT OF A SMART CITY CONCEPT IN VIRTUAL REALITY ENVIRONMENT

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Commission V, WG V/7

KEY WORDS: Virtual Reality, Smart City, 3D City Models, Unity, Geovisualization.

ABSTRACT:

There is an increasing interest in smart city concept as a technology-based alternative to conventional urban planning approaches. The design and implementation of smart cities require multidisciplinary efforts. As one of the first examples, a smart city concept was developed in Turkey in the year 2018 in collaboration with researchers and experts from various disciplines, such as geomatics and civil engineers, architects, computer scientists and urban planners. The developed concept aimed at designing a city district that targets sustainability, human-centricity, smartness, and safety, along with a sense of place and reflects local expectations in an unconstructed sub-urban area. In the project, the collaborative design process and the usability issues of the presentation environments have been of importance for geomatics professionals. Within the study, the existing settlement areas were modelled by using aerial photogrammetric data and combined with elements designed in various Computer-aided design (CAD) software. In this paper, the smart city design elements, which originate from the design principles such as ensuring nature conservation, green, cultural, safe and smart living spaces, and social responsibility, are explained briefly. The city was presented to the stakeholders via Unity game engine for a realistic experience prior to construction. The potential of Virtual Reality (VR) environments for the design, modelling, and visualization of very high detailed smart city concept is presented and various issues are discussed. The model experiment videos with VR, web-based model and project video can be accessed via the web page www.bizimsehir.org.

1. INTRODUCTION

In parallel to the rapid population growth and urbanization, cities are changing and expanding day by day. In recent years, the concept of smart cities has gained an increased importance as an approach to improve city management and to enable sustainable urban development. With the advancements in the Internet infrastructure and the Information and Communication Technologies (ICT) over the last decades, the concept of smart city has become a global phenomenon that affects both small and large cities. However, national and local governments need to develop novel technologies and innovative solutions to realize smart city goals. The concept of smart cities refers to a development of digital cities based on ICT infrastructure and Internet of Things (IoT), cloud computing, and Big Data technologies (Wu et al., 2018). Creating smart, sustainable, and resilient cities of future will require understanding how each city operates, formalizing that knowledge, and applying it to an appropriate city model as a basis for simulations that can generate scenarios for the future (Schmitt, 2013).

The efforts for the conceptual design of a smart city involve 3D modelling of the envisioned designs and transform into virtual environments. Smart cities aim to facilitate the city management through automated predictions based on data and decisions by reducing human intervention (Jamei et al., 2017; Buyukdemircioglu and Kocaman, 2020). It is a concept that attracts the attention of countries. Massive amounts of efforts have been dedicated for developing the smart city solutions, adapting to changing conditions, and directing this dynamic process. A multidisciplinary approach is required for the conceptual designs and planning of smart cities. The implementation of realistic smart city concepts should include existing urban structures as well.

Creating smart and sustainable cities requires an enormous amount of data collection and processing. The requirements of large-scale city design involve professionals from a wide range of fields as well as users, policy-makers, community representatives, etc. The stakeholders need to be able to comprehend this vast amount of data types. The smart city design and development require multidisciplinary approaches that encompasses many domains and disciplines. However, it was firmly rooted in computer science and engineering, with an emphasis on how technological advancements may be applied in cities (Lytras and Visvizi, 2018). In recent years, there has been an increased interest among research communities in constructing 3D models of smart cities based on 3D buildings (Yang and Lee, 2019).

3D city model visualization requires a specific approach when compared with the other data visualization techniques. Visualizing massive amount of data requires performance optimization of building geometries and textures. Digital twins for smart cities can be generated and visualized in real time using game engines (Clark et al., 2020). Game engines like

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Unreal Engine (Epic Games, 2022) allows users to combine 3D geospatial world with game engines by supporting features like WGS-84 coordinate system, photogrammetry models, high-resolution terrain, imagery and 3D city models with APIs (Cesium, 2022).

Virtual Reality (VR) is best known for its popularity in the gaming world. It has been increasingly used in other fields, including aerospace, healthcare, education, and urban planning. With a continually growing population, cities are becoming smarter and more complicated as their resources are stretched. The use of game engines and VR technology has advantages, such as providing an improved visual experience of the design and real world together. VR provides urban planners a powerful tool to visualize the effects of prospective projects on infrastructure and the environment. Smart cities will be impacted greatly by VR, especially as it relates to urban design. Participating in planning and design process can be enhanced with VR. Additionally, stakeholders from different disciplines can be involved in project design using this platform.

In 2018, a smart city concept design project was initiated by the Ministry of Environment and Urbanization (MoEU), Turkey as a collaboration between professionals and researchers, such as geomatics and civil engineers, architects, computer scientists and urban planners (MoEU, 2018). A general view of the smart city concept is given in Figure 1. The main design principles were defined as ensuring nature conservation, green, cultural and human-oriented, safe and smart living spaces, and social responsibility. A team of geomatics professionals contributed to the project for building the 3D models of existing settlement areas and merging with the designs, producing the 3D city model in different formats (e.g. CityGML) and presenting in different geovisualization environments such as 3D web, game engines, VR, etc. for enabling the collaborative design process and improving the communication between the different stakeholders for obtaining proper feedback.

Figure 1. An overview of the developed smart city concept (MoEU, 2018)

This paper aims at explaining the different design stages in detail, summarizes the lessons learnt in the collaborative design process, and describes future improvements to it. The literature review given in Section 2 focuses on the use of VR, AR, and game engines in smart cities. In Section 3, the smart city components and challenges are explained. Section 4 summarizes the 3D city model generation process, and discusses the visualization environments. The paper is concluded in the last Section.

2. RELATED WORK

A smart city, from the perspective of geomatics, combines a digital city, IoT, and cloud computing technologies (Li et al., 2013). Increasingly, geospatial data, new products, geoservices, and applications are being developed by government agencies and ministries, corporate giants, and software developers to engage urban users and citizen science (Tao et al., 2013). GIScience and geographical data are important components of smart cities, and GIScience has contributed a number of directly relevant challenges mentioned above, as shown by a literature search (Degbelo et al., 2016). A transition to smart cities is a necessary step for achieving sustainability in cities around the world, and as the city, citizens, and communication networks feed information into the system in real time, sensors play an important role to collect relevant information (Ramirez-Moreno et al., 2021). Hancke et al. (2012) gave a detailed overview of smart city sensing, sensing platforms, as well as the technical challenges related to the technologies.

By generating, visualizing, and localizing three-dimensional landforms on a user-driven basis, Carbonell-Carrera et al. (2020) analyzed the effectiveness of Unity3D for geospatial training. Laksono and Aditya (2019) presented their findings as part of their research exploring Unity3D for presenting large-scale topographic data from multiple sources, such as Level of Detail-1 (LoD-1) and LoD-3 buildings, road and place name layers, and MapBox for Unity for georeferencing. Huo et al. (2021) visualized large-scale oblique photogrammetry models with an improved efficient approach using Unreal Engine. Using game engine applications for visualization and dissemination in real time, Merlo et al. (2013) studied the visual and interactive representation of cultural heritage. Their pipeline provides the development of modeling and texturing procedures, which convert/optimize dense point clouds into low-poly texturized models within game engines that can be imported easily.

Museums can also be explored virtually through VR technology (Kersten et al., 2017). By integrating the different types of information into real-time visualizations, VR becomes a powerful tool for educational applications at museums beyond being just static virtual worlds (Walmsley and Kersten, 2020). Using eye-tracking experiments, VR simulations are being used to examine human movement in perception and cognitive processes through visual perception (Kim and Kim, 2020). Data exploration tasks are analyzed from a user perspective using three existing web platforms and the proposed VR application in order to evaluate perceived workloads and data immersion parameters by Broucke and Deligiannis (2019).

Bellalouna (2020) presented and discussed a VR application for efficient factory planning, in which users are able to fully immerse themselves in the virtual environment that represents the factory and can intuitively interact with its equipment. A workflow developed by Wallmsley and Kersten (2019) was used to create an interactive, immersive experience of a 3D historical environment model of the town of Stade (Germany) in the year of 1620, where the developed model contains detailed and realistic details with a high degree of realism in a VR environment. Bouloukakis et al. (2019) proposed a smart city visualization framework in VR environment for visualizing and monitoring smart cities.

The models can be visualized on different platforms, in which technologies such as VR (Tschirschwitz et al., 2019), Augmented Reality (AR) (Yagol et al., 2018) or Mixed Reality (MR) (UrbanX, 2018) offer various ways of data visualization and data interaction. In some areas, such as the development of smart cities, urban decision-making, and public participation, AR technologies may improve engagement between citizens and authorities (Sanaeipoor and Emami, 2020). A case study conducted outdoors involving an AR system for thermal target detection in a façade inspection task has been presented and evaluated by Liu et al. (2020). A mobile visualization application was developed by Santana et al. (2017) to display the results of different simulations and models of energy related simulations at building level using VR and AR environments.

3. SMART CITY MODELING CHALLENGES

In order to design the smart city concept called Bizimsehir, an area of 287 hectares was selected in Gaziantep, Turkey. The photogrammetric data employed in the project was provided by the MoEU. More information about the study area can be found in our previous study (Buyukdemircioglu and Kocaman, 2020). Within the project, the landscape plans and city furniture were converted and incorporated into the final model along with the building models. Several design elements existed in the model, such as vegetation, city furniture, transportation structure, as well as sensors and animations. This section provides a detailed explanation of the smart city concept, as well as the problems and solutions encountered during the model implementation.

3.1 Bizimsehir Smart City Components

The model elements of Bizimsehir represent several smart city components and design principles, such as renewable and alternative energy sources, instant communication through technological devices, mobile applications and interactive platforms, and reduced human labour, etc. (MoEU, 2018). The designed district administration is assumed to be controlled from a central hub containing several management units. In the administration centre, the collected data is subject to evaluation by software algorithms and personnel. Data related to energy and water consumption, waste management, air quality, and traffic are assumed to be collected and recorded through the IoT sensors and analyzed at the administration centre. In addition to online monitoring, the efficiency and security analyses are considered to be carried out via a geographic information system (GIS). The overall objective is to ensure efficient natural resource management, reduce environmental pollution, and increase the synchronization between various city elements. From the perspective of smart city components, the detailed 3D model elements can be categorized as smart buildings and IoT sensors for smart transportation, air quality monitoring, waste and energy management, health services, and green spaces. A view from the detailed 3D model is given in Figure 2.

Regarding smart buildings (MoEU, 2018), it was envisioned that each building will have a control room for monitoring the energy consumption the heating and cooling will be monitored automatically and maximum efficiency will be achieved while using the minimum amount of energy. Photovoltaic solar panels and wind energy systems are planned to be installed on the rooftops to produce renewable energy. Solar panels will also be installed on parking lots, light poles, and other suitable locations. With the help of these panels, electrical energy will be produced for city lights and the other energy-consuming tasks.

Figure 2. A view from the detailed 3D model of Bizimsehir.

The smart transportation elements mainly include specifically designed bus stops and bicycle utilities as essential means. The bus stops are planned to be equipped with information screens to provide city residents with real-time information on traffic and travel conditions; and several IoT sensors such as cameras for safety and management of parking systems (Figure 3). In order to manage traffic, control boxes will be located at each intersection, along with various sensors built into the lighting mechanisms. A digital information screen at each stop will provide users with contact information, live bus location information, a city map, and ticket purchase options. Additionally, the bus stops will feature USB charging stations and sensors for monitoring air quality.

Figure 3. Designed smart bus stop for the smart city concept

Measurements of air quality and sound noise will be done via IoT sensors located throughout the district (MoEU, 2018). On information screens in the city, residents will be able to view live air quality and sound noise information. By using garbage containers hidden underground and reporting the occupancy rates with sensors, garbage collection will be carried out effectively with route optimization. The establishment of a separation facility will allow for the recycling of different types of waste (paper, glass, metals, chemicals, etc.). For smart health solutions, mobile apps will be primarily used to provide access to quality of life control, emergency notifications, and examination results. Electronic signs will provide guidance and information on epidemic diseases throughout the city. The use of wearable health products will enable elderly and disabled individuals to be automatically noticed and intervened when necessary.

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Regarding green space management, IoT Sensors are involved to measure soil moisture for determining the amount of water that needs to be used. It will be possible to save a large amount of water with smart irrigation, and it will be an environmentally friendly approach. Rainwater collected in containers on buildings and roads will also be used for irrigation.

Considering the various design elements envisioned in the project (MoEU, 2018), as summarized above, the co-design process has been carried out iteratively. Integration of the individual design elements in the 3D model and conversion to the different presentation environments have several challenges, as briefly explained in the next Headings.

3.2 Model Optimization

A number of CAD software packages were used to design the model components. Highly detailed LoD3 building models, city plans, and city furniture were created by architects using Trimble SketchUp (Trimble, 2022). After the models were generated, they were imported into Autodesk 3DS MAX (Autodesk, 2022) in order to perform polygon optimization, scaling, georeferencing, texturing, and CityGML conversion.

SketchUp can be used to quickly generate highly detailed 3D city models, though some post-processing is needed because the models were not georeferenced and scaled for the urban plans. In addition, the number of polygons within the models needed to be optimized by manually removing unnecessary ones. The number of polygons reduced without causing any visual distortion on the models. Polygon count is an important factor that directly affects the visualization performance of models in real-time rendering environments, particularly in game engines (where the graphics card is used to produce a precise and efficient rendering of the entire model). Models should be represented with few polygons because each surface requires additional computing power on hardware, especially on the GPU. The model geometries were manually edited by considering their topological consistency.

Also, the texture quality is usually more important than the number of surfaces when it comes to representing the model details. The texturing process was carried out manually in 3DS MAX software for a lossless conversion. All texture data were converted from PNG format to JPEG using FME (Safe, 2022) for reducing their size. As the final step, the models were converted to CityGML format. Duplicates in textures have been removed and blended into atlases, then stored in CityGML. A view of generated textured building model with reduced polygons can be seen in Figure 4.

3.3 Georeferencing

Due to the missing geolocation and scale information, manual processing and coordinate transformations were carried out prior to integration. One issue in the process was architectural modifications to the building footprints during the detailed design process that caused inconsistencies between the building footprints and the urban plans. In most cases, buildings are designed as individual units; and they can be enlarged, shrunk, rotated, or moved by the architects to meet their needs. They are also modeled in a model (arbitrary) coordinate system without georeferencing. Due to the lack of support for projected coordinate systems in 3DS MAX, the models could not be directly integrated into the city model and a manual pre-processing step was essential.

Figure 4. A sample view of generated textured buildings from Bizimsehir (www.bizimsehir.org).

On the other hand, the 3DS MAX software supports coordinates consisting of up to eight digits including decimal characters. Therefore, an Earth referenced coordinate system could not be utilized in the tool directly and a local coordinate system with reduced coordinates by "shifting the plan to zero" was employed. Using the 2D urban plan developed by the urban planners, the 3D building models were manually placed on the urban plan with the same offset values. An overview of the georeferenced model is shown in Figure 5.

Figure 5. An overview of the georeferenced model (www.bizimsehir.org).

3.4 Adaptations for Game Engine

Model generation also requires the use of the surface normal (or normal vector) to identify the surface direction (front or back face). The direction of the normal vector depends on the order of the vertices and coordinate system (right- or left-handed). The surface of the model represents the thumb. When a surface is displayed in real-time, such as in a game engine, the surfaces can be doubled, which would increase the memory demands on the graphics card. When the surface normal points to the right, a stereo view is created because the graphic card shows two surfaces in the same location. Architectural models should be produced according to the requirements for real-time visualization (e.g., minimal polygons, compressed textures) in order to avoid potential visual problems. Individual files were created for the building objects and the other city elements including the city furniture. The files were then exported to CityGML using the CityGRID Modeler (UVM Systems, 2022).

In the last stage, the model units were merged and visualized with the Unity game engine. In order to ensure a realistic impression and for accurate positioning of the city models, true orthophotos were used as basemap. DTM (Digital Terrain

Model) also plays an important role for 3D city models. A high-resolution DTM (1 m or better) that is coherent with the building model is vital for avoiding visual distortions. Since using the actual DTM of the unconstructed project area would result in visual defects and result in incompatibility. Thus, the DTM of the study area was pre-processed to comply with future city model and urban plans. Implemented 3D city models with buildings, ground plans, and city furniture were also exported to Unity game engine that allowed users and stakeholders to achieve a unique and realistic visualization experience in a VR environment.

4. EXPLORING A SMART CITY WITH GAME ENGINES AND VIRTUAL REALITY

Game engines are graphics and programming-based environments used to create visually intense video games on consoles, mobile devices, and personal computers. Game engines also form an excellent platform also for displaying terrain in VR, since it provides the functionalities necessary for the user to become immersed in the virtual environment. Since Unity requirements were taken into consideration at the model implementation stage (georeferencing, scaling, etc.), all objects generated in 3DS MAX could be converted into Unity with their position, rotation, and scale information using Autodesk FBX files without any loss. Several materials per mesh were exported with vertex colors, normals, and textures. Moving and sound effects, such as people talking, trees swaying with the wind, etc., were added to simulate a lively feeling. A more realistic experience when exploring the city model was provided at street level, along with the addition of footstep sounds while moving in the city.

The use of VR and game engines has certain advantages, including improving the visual experience of users for by combining the reality with the designed environment, providing animations, sounds, and a more flexible ability to interact with it. In a VR environment, users can connect the urban design features of cities to interact with their surroundings through analysis and the simulation of user behaviour. VR enables planners to evaluate the potential impacts of new developments such as transportation, environmental and other features of the city. The stakeholders of the design process could support an improved understanding of the design outputs and comprehend the pros and cons as well as the interaction of their individual designs with those from the other teams. Designers, city planners, and other stakeholders may be able to collaborate on shared virtual architectural models with social VR, which brings people together in a virtual world. For architects and other stakeholders, VR provides the means to visualize interior and exterior elements, considering the many factors that have an effect on construction and design. VR could assist architects and planners in making more informed decisions regarding urban design, as it can be used in creating better footpaths, improving public transport, and preserving historic buildings. Increasing accessibility of VR technology will lead to widespread adoption of virtual reality in urban development.

It is necessary to use special hardware and software for VR technology to explore the model, such as VR-ready GPUs and VR headsets. Our study utilized the HTC Vive virtual reality headset (HTC Vive, 2022), Unity game engine (Unity, 2022) with SteamVR (SteamVR, 2022), and GeForce GTX 1080 GPU to explore our generated smart city concept. Views from the exploration of the smart city with VR are given in Figure 6.

Figure 6. VR experience for exploring Bizimsehir with HTC Vive VR headset.

The VR experience goes beyond 3D modelling and visualization. The VR technology can replicate the design in the modelled reality, and enable users to feel as if they are physically in it. 3D models show a space in detail; but VR allows people to virtually interact with that space. Through VR, users can see the future home they will live in as well as the surrounding area (nearby buildings, nearby parks, pedestrian traffic on footpaths, vehicular traffic on streets). Users can move around the city as if there are in the city. VR can be used to simulate light, heat, security features, security and access controls to assess their impact and identify potential improvements. The VR experience allows citizens to provide more insightful feedback.

As part of the developed smart city concept, it was possible to explore the model at street level. Aside from the street-level view, a flight mode was also available to tour the city and view objects such as building roofs and electricity poles that can be hard to see from ground level. The smart city concept in the VR included hotkeys for teleporting to city squares and parks in order to get around quickly. Visual effects in a scene also enhances the feeling of liveliness, also increase the sense of realism. Through such approaches, an improved understanding of an environment could be achieved, such as knowing the city noise level at a certain location through a simulation. Views from the VR model are given in Figure 7.

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Figure 7. Views of city centre at street level (a), city furniture (b), animated citizens (c), and flying mode view (d).

5. CONCLUSIONS AND FUTURE WORK

This study presents the 3D model production and visualization efforts from the first smart city design project in Turkey from a multidisciplinary perspective. The challenges encountered during the model production and their solutions, as well as format conversions and optimization processes, are discussed. Elements such as smart transportation across the city, rain water harvesting, smart farming, etc. were considered during city design. A number of smart solutions were planned to be offered related to energy and lighting, wireless motion sensors, power-saving street lighting, etc. In addition, the city shall have IoT sensors for all elements such as buildings, health, energy, lighting, irrigation, transportation, waste management, bus and tram stops, and air quality. The city was assumed to be monitored from a central administration center, and a smart management room integrated in each building. Thus, the 3D smart city model involved various details and components beyond the buildings.

Considering the amount of details and the communication requirements between the different parties during the co-design process, detailed 3D models were required and presented in different environments. The implemented LoD-3 smart city model was visualized in the unity game engine using VR technology. Games engines are primarily used to visualize 3D objects in an environment where users can interact with them using the physics engine, which can include features such as sounds or animations. They utilize a GPU, which allows for a more detailed visualization, and provide higher frames per second (FPS) than web-based visualization. With the advent of game engines and VR hardware, researchers can apply the knowledge gained from traditional simulation techniques to visualizing smart city concepts in real time.

As the technology advances, VR will play an increasingly important role in filling the gap between the technological and the real world. The use of VR can assist in overcoming visual barriers, allowing people to see projects on a larger scale and provide more involved, detailed feedback and designs. Participatory planning promotes collaboration between many different groups of stakeholders to achieve a common vision for urban and rural planning, and to overcome conflict and harmonise viewpoints. Using the VR technology, interactive environments can be created in which people can interact directly. Thus, the quality of their feedback also improves and allows them to visualise, communicate and evaluate new developments. The use of VR, AR and MR technologies is still an open research area for the visualization of geographical data and smart city concepts.

As a future work, building interiors (LoD-4) can be designed and incorporated into the model. Game engines such as the Unreal Engine can also be used as an alternative to Unity for presenting smart city concepts. User interaction with the environment and the other people in the scene can be added within the game engine.

ACKNOWLEDGEMENTS

The authors would like to thank Alpaslan Tütüneken for providing CityGRID software and the Ministry of Environment and Urbanization for providing the data and funding the project. The authors are also grateful for having the possibility to collaborate with the Bizimsehir Gaziantep project team. Mehmet Buyukdemircioglu acknowledges the support of the Scientific and Technological Research Council of Turkey (TUBITAK) 2214-A International Doctoral Research Fellowship Programme, 2224-A Grant Program for Participation in Scientific Meetings Abroad and Higher Education Council of Turkey (YÖK) for 100/2000 Ph.D. research scholarship. The paper is part of the Ph.D. thesis research of the Mehmet Buyukdemircioglu.

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