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THE APPLICATION OF CITY-BUILDING GAMES IN SPATIAL PLANNING

Dissertation thesis

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Author's statement

I declare that this PhD thesis of P1031 Geography study program has been completed independently and under the supervision of doc. RNDr. Jaroslav BURIAN, Ph.D. All the materials and resources are cited with regards to the scientific ethics, copyrights and laws protecting intellectual property. All provided and created digital data will not be published without the consent of the Department of Geoinformatics, Faculty of Science, Palacky University Olomouc.

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CONTENTS

LIST OF ABBREVIATIONS

CAD	Computer Aided Design
GIS	Geographical Information System
Mod	User-made game modification
DLL	Dynamic link library
DLC	Downloadable content (game addition)
CSV	Comma Separated Values (file format)
WKT	Well-known Text (geometry format)
KML	Keyhole Markup Language
OSM	Open Street Map
DEM	Digital Elevation Model
DMR 5G	Digitální Model Reliéfu 5. generace (5th generation of the Czech national DEM)
SRTM	Shuttle Radar Topography Mission
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
RÚIAN	Registr územní identifikace, adres a nemovitostí (the Czech national property register)
DIBAVOD	Digitální Báze Vodohospodářských Dat (the Czech national database of water resources)
API	Application Programming Interface
GDAL	Geospatial Data Abstraction Library
WGS	World Geodetic System
UTM	Universal Transverse Mercator

1. INTRODUCTION

Spatial planning is an interdisciplinary field which affects a wide range of human activities and is an essential part of managing and organizing today's developed urban areas. The processes of spatial planning are often very complex and involve many stakeholders such as municipality and town or district representatives, property owners and investors. Therefore, spatial planners use numerous tools which help them facilitate communication among stakeholders, propagate information, model scenarios, engage local citizens, etc. One of the types of tools that have been used in this regard are games.

Games are an integral part of our culture, mostly due to their entertaining qualities. Nevertheless, games can also be used for non-entertainment purposes. Since the second half of the 20th century, games have begun to be utilised in the field of spatial planning to simulate urban-related processes, but also as an experimental educational tool or for facilitating participation and communication among stakeholders. Different types of these games include board or card games; pervasive games, which are often played outside in the urban environment; and finally, digital computer games. Whereas non-digital games have remained essentially unchanged, digital games have evolved drastically due to the rapid development of information technologies.

City-building games represent a specific genre of digital games in which the player engages in various activities of spatial planning by building and managing a virtual city. Today's city-building games provide visually appealing 3D environments, agent-based simulations of city-related processes as well as the possibility of modifying the game's behaviour. Due to these features, city-building games have begun to be used in non-entertainment ways, e.g. as an educational tool, for simulating various scenarios or for engaging citizens. Therefore, this dissertation thesis investigates the potential of modern city-building games for practical use in the field of spatial planning.

2. OBJECTIVE OF THE THESIS

The main objective of this dissertation thesis is to create a real-world model in a city-building game from geographical data and to then investigate and test the possibilities of the application of this model for the purposes of spatial planning.

At the beginning of this work, city-building games with the potential to be used for the purposes of spatial planning will be selected. Primarily, this work will focus on uses in urban modelling, visualisation, or for facilitating civic engagement. As part of this objective, a set of criteria will be defined for the selection of the game with the highest potential for its application in spatial planning.

Importantly, in order to use a city-building game for the purposes mentioned above, the game environment must provide a realistic representation of a real-world place or offer options for creating one. This is usually completed using methods or tools for processing geodata (e.g. importing geodata into the game). Therefore, in the practical part of this work, new tools for geodata processing will be developed for the selected game. Using the newly developed tools, geographically accurate models of selected cities will be created.

Next, this work will explore possible advantages and disadvantages of the created models in selected case studies, which might include:

- using the models for simulations of urban-related processes
- using the models for 3D visualisations of proposals from the master plan
- using the models for the geo-design of a selected area (participation project)

At the end, the dissertation thesis will evaluate the case studies and the overall contribution of the created models as well as the developed tools.

The dissertation thesis should answer the following research questions:

- Can the creation of a game model be automated from a geographical data source?
  - Objectives 2 and 3 will address this question.
- Can a city-building game be used as a tool for designing proposed development activities?
  - Objective 4 will address this question.
- Can a city-building game be used as a visualization tool for presenting proposed development activities to the public?
  - Objective 4 will address this question.

- Can a city-building game be used for the simulation of city-related processes?
    - Objective 4 will address this question.

The dissertation thesis has 4 objectives.

OBJECTIVE 1 – Selection of a city-building game with the highest potential for its application in spatial planning

There are numerous city-building games to choose from. However, not all games can be efficiently used for the purposes of spatial planning. Objective 1 is to select a city-building game with the highest potential for its application in spatial planning. In order to select a game with the highest potential for its application in spatial planning, a set of criteria will be employed. These criteria will include:

- Attractivity: the selected game should attract a larger audience (e.g. in a civic engagement scenario).
- The possibility of modifying the game: the selected game should offer options for modifying its looks and behaviour (e.g. to achieve more realistic simulations).
- Sufficient game space: the selected game should be able to present real-world places without significant distortion (e.g. the game must operate in 3D space).
- The possibility of processing geographical data for game world creation

OBJECTIVE 2 – Development of geodata processing methods and tools for game world creation

The main focus of this research is given to city-building games with representations of space. City-building games usually operate in imaginary spaces that do not reflect the real world. Though many players have manually created models of various places on Earth in city-building games, the accuracy is often insufficient and the creation process time consuming. If city-building games were to be used for visualisation, participation or simulation projects, the creation of the game world representing a real-world space must be accurate, fast, simple, and repeatable. Objective 2 is to develop set of methods and tools which process geographical data for the selected game. The developed tools will create game objects such as roads, trees, zoning, etc. from the source geographical data, making the overall model creation process more accurate, simpler, and faster. Additionally, the developed tools will also allow for exporting the game objects into a GIS format which can be processed further (e.g. for a data collection participation project). As part of this objective, list of geographic data that can be imported into the selected game will be provided.

OBJECTIVE 3 – Creation of models in a selected city-building game

In order to use a city-building game for the purposes of spatial planning, a model representing a real-world place must be created (apart from use in educational settings, where the use of models of imaginary cities is sufficient). The created model must be completed with the highest achievable accuracy. Objective 3 is to create a model (or models) of an urban area in the selected city-building game. First, a suitable urban area will be selected. Next, geographical data will be collected and pre-processed for this area. Using the geodata processing tools developed as part of Objective 2, a base model will be created, consisting of game objects such as roads, buildings, zoning, trees, etc. Generated base models might include errors, e.g. due to incorrect geographical data. These errors will be fixed as part of post-processing of the base model. Moreover, the generated model will be calibrated in accordance with the game's requirements. The resulting model will provide a standard gaming experience.

OBJECTIVE 4 –Utilisation of playable models for spatial planning

The created model in Objective 3 will represent a selected urban area and as such can be utilised for purposes of spatial planning. The following uses of a city-building game will be considered:

- As an urban modelling tool
- As a visualisation tool
- As a tool facilitating civic engagement

Objective 4 is to conduct case studies that will employ the created playable model for purposes of spatial planning. All of the use cases will be documented. In case studies involving participants, feedback (such as qualitative questionnaire) will be collected, and the responses discussed.

Structure of the dissertation thesis

First, the topic and objectives of the dissertation thesis will be introduced. Next, a current literature review of the following areas will be described: games, serious gaming, the city-building genre, and the use of city-building games in spatial planning. As part of Objective 1, a city-building game with the highest potential for its application in spatial planning will be selected. As part of Objective 2, new tools for processing geographical data for the selected game will be developed. Additionally, geodata for a selected area will be pre-processed for the purposes of the developed tools. Objective 3 will be divided into two main parts: creating the base model and finalising the model so it provides a full gaming experience. The base model will be created by using the newly developed tools and pre-processed geodata. The resulting playable model will be completed with manual post-processing. Objective 4 will consist of conducting case studies in which the resulting model will be utilised. Figure 1 shows the schema of the dissertation thesis.

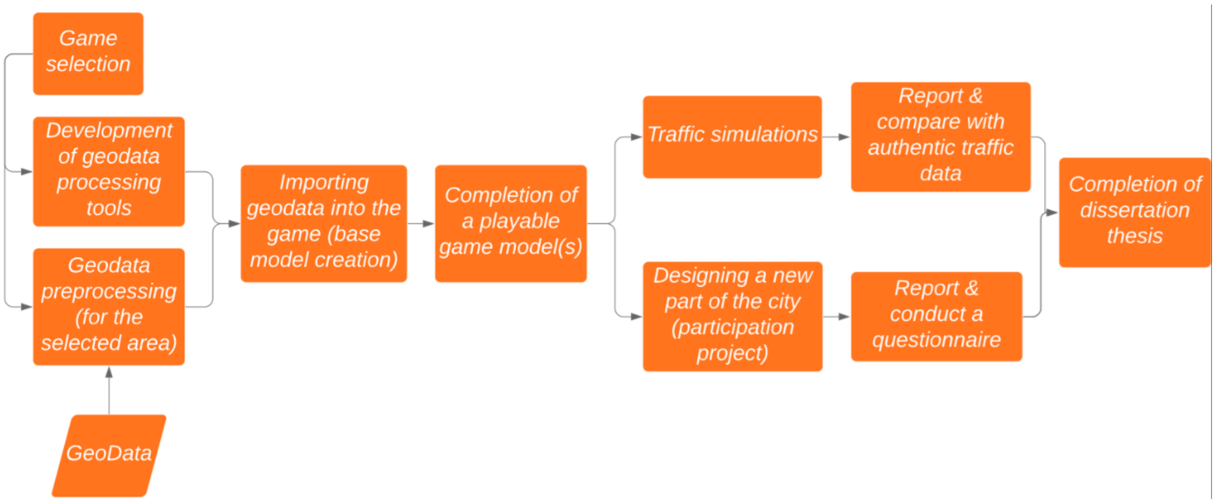

Figure 1 Schema of the dissertation thesis.

3. METHODS AND DATA

This section mentions the most important methods, software and data used in the thesis. Furthermore, it provides basic information about the area of interest. More information about the used methods and data is written in corresponding sections of the thesis.

3.1 Methods

Appropriate methods were selected to fulfil the goals of each objective of the thesis. First, as part of Objective 1, a game with the highest potential to be utilised for the purposes of spatial planning will be selected. Several commercial city-building games were considered for further research. Serious games were not considered because they often serve a specific non-repeatable purpose. The selection of the game was based on several aspects such as the game's attractivity, the modding capability or the capability to simulate city-related processes. These aspects were represented in the following criteria used for the game selection:

- Attractivity (in number of copies sold)
- Attractivity (in number of subscribers of the user forum dedicated to the game)
- Provides city-related simulations
- Previous uses in spatial planning
- Provides 3D space representation
- Provides a modding environment
- Provides modding support
- Enables geodata processing

Based on these criteria, a city-building game with the highest potential for its application for spatial planning was selected. The selection process is described as part of Objective 1 in section 5.

The first goal of Objective 2 is to provide a solution for the automated, accurate and simple creation of a game model from geographical data. The second goal is to provide a solution for accurately exporting game objects into a GIS format. Completing these two goals will enable two-way migration of data between the selected game and GIS tools.

New geodata processing tools were developed in order to achieve the goals mentioned above. The development of new tools was completed in the modding environment of the selected game. The game's coordinate system was investigated to find the most fitting conversion of geographical coordinates to game coordinates and vice versa. The coordinate conversion algorithm was then incorporated in the developed tools.

An additional goal of Objective 2 was to create a set of methods for pre-processing geographical data that were subsequently used for generating game objects. Games do not provide options for working directly with GIS data formats such as Esri's Shapefiles, GeoJSON or Google's KML. Therefore, the source data were converted into a simple comma separated value (CSV) file. The geometry of the geographical object was recorded in a Well-Known Text (WKT) format. Also, the source data were filtered to provide only the information that is valid and required by the selected game. The development of geodata processing methods and tools is described as part of Objective 2 in section 6.

The tools developed in Objective 2 were used to generate objects in the game, creating a base model of the selected area. Additionally, post-processing of the base model was required to create a final model which provides the full gaming experience. Manual post-processing consisted of these stages:

- Adding water resources
- Fixing the road network
- Creating zoning
- Mitigating unrealistic simulation behaviour of the game
- Creating a public transport system
- Adding playgrounds, sport grounds, parks, and unique buildings such as churches and skyscrapers

To complete these stages, numerous game mods were utilised. The game mods helped with fixing the data-related issues as well as with the configuration of the game's simulations. The whole process of creating a model is described as part of Objective 3 in section 7.

The model created in Objective 3, representing a selected urban area, was utilised for the purposes of spatial planning in two case studies:

- Designing a new neighbourhood in a geo-participation project
- Simulating traffic

The first case study, designing a new neighbourhood in a geo-participation project, was organized as a contest where players were invited to submit a design of a new neighbourhood. The rules of the design contest were based on the conditions stated in the city's masterplan for the selected city area. The collected designs were then assessed by a jury of experts in spatial planning. Finally, feedback on the design contest was gathered from both the players and the experts.

In the second case study, the model was further optimized to efficiently simulate traffic (assigning priority roads, adding timed traffic lights, adjusting the traffic simulation logic, etc.). To accurately monitor the simulated traffic density of the model, an additional game mod was developed. Using this mod, roads with the highest traffic density were identified. Next, the simulated results were compared with authentic traffic data. Additionally, the model was modified to replicate planned developments of the road network. The traffic density was then monitored before and after the modification and the results compared. Both case studies are described as part of Objective 4 in section 8.

3.2 Data

Because of using a CSV format for importing data into the game, any source of geographical data can be used. Open Street Map (OSM) data was used predominantly for generating the game objects. Data from local authorities were used for modelling urban areas of the selected cities in the Czech Republic. Global digital elevation model (DEM) datasets were used for creating a terrain in the game models. In general, the use of freely available data was preferred. The following data sources were processed:

- DIBAVOD as a source of vector data of rivers and other water resources.
- DMR 5G, SRTM3 v4.1, SRTM30 Plus or ASTER 30 meters for modelling terrain within the game
- OSM as a source of vector data of roads and railways.
- RÚIAN as a source of vector data of buildings in the Czech Republic
- Urban Atlas Street Tree layer or CORINE land cover layer as a source of vector data of forested areas in Europe
- Zoning data from a selected city, e.g. data set Functional Zones Olomouc
- Bus and tram lines schedules published by Dopravní podnik města Olomouce

Additionally, following data sources were used for simulating traffic:

- HERE Traffic API for monitoring authentic traffic data
- Proprietary dataset of road network and districts of the city of Olomouc

3.3 Software

The main software used in the dissertation thesis was the selected city-building game. Geographical data were pre-processed in QGIS and ArcGIS Pro. OSM data were obtained using the web service OverPass.API. OSM data were processed using the open source library OSMSharp or QGIS. The open source conversion library GDAL was used for generating raster heightmaps from available DEM datasets. The developed tools were programmed in the language C#.

QGIS

QGIS is a free and open-source desktop GIS software that supports viewing, editing, and analysing geographical data. QGIS runs on these platforms: Microsoft Windows, Linux, macOS and Android. QGIS was written in the programming language C++. QGIS includes a Python console which enables the user to script a solution for processing geographic data. QGIS also includes the Geospatial Data Abstraction Library (GDAL) and thanks to that can read and write multiple geographical data formats. QGIS version 3.8.3 - Zanzibar was used for the purposes of this dissertation thesis.

Visual Studio

Microsoft Visual Studio is an integrated development environment (IDE) from Microsoft. This IDE can be used for almost any programming language, creating desktop programs, web, or mobile applications as well as custom modifications to games (game mods). The freely available community edition, version 2019, was used in this dissertation thesis to develop game mods.

ArcGIS Pro

ArcGIS Pro is a market-leading commercial GIS software developed and maintained by Esri. ArcGIS Pro is used for viewing, querying, and editing geographical data, creating, and using maps, running data analysis, etc. In ArcGIS Pro, the user can also connect to multiple data services hosted on ArcGIS Online.

OSM and OverPass.API

Open Street Map (OSM) is a collaborative project to create a free editable map of the world. OSM provides mapping of roads, buildings, services, water resources, types of land, etc. Data provided by OSM can be viewed in a web browser, with a route navigation software such as OsmAnd or in a GIS software such as QGIS (using an extension). OSM data can be downloaded in numerous ways. One of the most popular ways is using the service OverPass.API which will download the whole dataset for the bounding box specified in the OSM XML data format. The OverPass.API query can look like this:

http://www.overpass-api.de/api/xapi?map?bbox=17.2593,49.5893,17.2706,49.5964

3.4 Area of interest

The main area of interest of this thesis is the city of Olomouc, Czech Republic, and its surroundings. The city of Olomouc (Czech Republic) is the 6th biggest city in the country, with a population of 100,514 inhabitants(Havel, 2021). This city was selected for this research for its history and size.

The size of the modelled area corresponds with the size of the gaming area, which is 17.28 km x 17.28 km. The selected centre of the area is 17.247812, 49.588705 (longitude, latitude). The area covers the majority of the Olomouc municipality (a small part near the town of Hlubočky is not included). Figure 2 shows the boundary of the modelled area in black and the border of the Olomouc municipality in red.

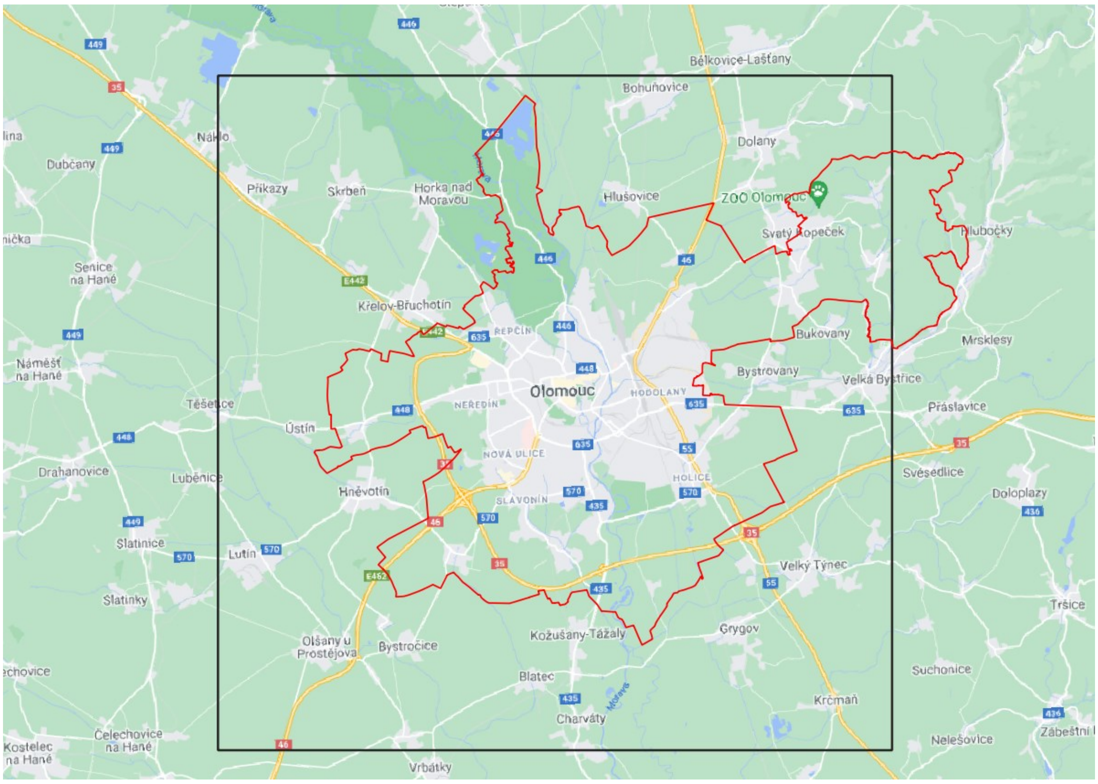

Figure 2 Area of interest (in black) and boundary of the Olomouc municipality (in red).

4. LITERATURE REVIEW OF THE PRESENTED TOPIC

The history of spatial planning is related to the foundation of cities and their development. Various forms of spatial planning can be observed throughout history, from building pyramids in ancient Egypt, to constructing fortified cities in the Middle Ages, to the continuous development of megacities in the modern era. Today, spatial planning is an essential part of organising and managing public administration. Spatial planning involves many stakeholders: representatives of the municipality and the general public, property owners and investors. In the negotiation process, the involved parties must come to an agreement that is acceptable to all and which also balances three aspects: economic, environmental and social. Another challenge is the growing complexity of today's urban areas as an increasing number of people migrate from rural areas to cities ("World Urban. Prospect. 2018 Revis.," 2019). Because of these challenges, spatial planning requires more information, methods, and tools. Fortunately, with the advance of information technologies, numerous tools have been developed to help spatial planners with their work, such as databases for archiving large amounts of information, GIS and CAD software for capturing spatial information, or a wide range of modelling tools for simulating different scenarios to support decision making.

Modelling is a basic concept used for understanding a studied system. Simulation modelling, as one of the types of modelling, provides an option for testing a wide range of scenarios in the studied system. The knowledge gained from running the testing scenarios can then be used to predict the system's behaviour in the future. The three main methods of simulation modelling include: system dynamics, discrete event modelling and agent-based modelling (Grigoryev, 2015). Simulation modelling is widely used in spatial planning for tasks such as simulating land use, transportation, traffic, or environmental planning. Popular software applications with a focus on simulation in spatial planning include: What If? (http://whatifinc.biz/), MATSim (https://www.matsim.org/), PTV Visum (https://www.ptvgroup.com/) or UrbanSIM (https://urbansim.com/). These programs are a great asset for professional city planners but are often too complex for a wider audience. For example, in situations such as presenting city plans to the public, coordinating communication among stakeholders, or teaching principles of spatial planning to students, it is preferable to use a less complicated, more attractive tool. Therefore, numerous urban planners have started employing games as the optimal tool for the cases mentioned above.

The concept of utilising games was brought to the field of spatial planning in the second half of the 20th century. Richard Duke, one of the pioneers of simulation gaming in spatial planning, developed a game, Metropolis, which simulated communal budgeting for supporting consensus-building among stakeholders (Duke, 1964). Another early urban-related game, The Cornell Land Use Game (CLUG) was a non-digital board game that was designed to support planning processes (Feldt, 1972). Digital urban games developed in the 1960's and 1970's utilised large-scale models for their simulations. These simulations however, turned out to be largely inaccurate and failed to provide conclusive outcomes (Lee, 1973). Despite feeling disillusionment about the simulation capabilities of large-scale models, many scholars looked for other uses of games in the field of spatial planning, such as facilitating participation and communication among stakeholders (Armstrong & Hobson, 1972).

An important reason for the continuous effort toward employing games in the field of spatial planning is also their immense attractivity, especially in the case of modern digital games. According to a recent survey conducted by the Pew Research Center, 90 percent of surveyed teenagers play video games of some kind either on a cell phone, computer or a console (Anderson & Jiang, 2018). However, games are attractive to almost everyone and not just teenagers. A market study from 2010 reports that the serious games market is worth 1.5 billion € (Alvarez et al., 2010). As for commercial games, the profits are growing every year, in 2018 reaching $2.4 billion (*Market Brief - 2018 Digital Games & Interactive Entertainment Industry Year In Review*, 2018).

Because of the reasons stated above, games are being utilised in the field of spatial planning in several ways: for teaching and education, for engaging the public and other stakeholders, for visualisations, geo-design or for experimental simulations. This dissertation thesis focuses on utilising commercial city-building games "seriously". In the following text, the term serious games and the "serious" use of a commercial game will be explained. Subsequently, an overview of the city-building game genre and its use for the purposes of spatial planning will be provided, specifically:

- as a learning tool in spatial planning classes
- as a tool for enabling participation in spatial planning
- as an urban modelling tool

4.1 Serious games and commercial video games

Games that were developed by scholars or spatial planners to solve a specific scenario, some of which were mentioned above, have begun to be labelled as "serious games". Clark C. Abt (1970) introduced the term "serious games" in his influential book of the same name, "Serious Games". Abt defines this term as games that "have an explicit and carefully though-out educational purpose and are not intended to be played primarily for amusement". Since then the term has evolved, incorporating any non-entertainment uses of a game such as simulation, propagation, visualisation or participation, and thus the term "serious games" could be simply rephrased as: games with a non-entertainment main goal. Djaouti, Alvarez, Jessel, & Rampnoux (2011) provide a comprehensive analysis of the former and current use of serious games. The term "serious games" helps to distinguish these types of games from commercial video games that are developed to be mainly entertaining and thus appealing for the player or potential buyer. For decades, serious games and commercial video games served different purposes. However, this started to change at the end of the 20th century when a few commercial games started to be used "seriously", i.e. with a main purpose other than entertainment. The prime example is the city-building game SimCity, which, in contrast to the majority of commercial games of that time period, took on the risk of implementing open-ended simulations of city planning processes. This game found its community and turned out to be commercially successful, proving that more realistic approach does not have to be limited only to "serious games".

4.2 City-building game genre overview

Most city-building games can be described as a single player open-ended game, where the player as an all-powerful mayor plans, builds and manages a virtual city. The objective of the game is not to reach a specific end goal but rather to build a prosperous city with satisfied inhabitants. While playing a city-building game, the player learns about city related processes and their dependency.

While limited in its simulation, The Summer Game, coded in 1968 by Doug Dyment, is considered to be the first computer game concerning city building and management (Moss, 2015). Several experimental titles followed but the big success came later with the release of SimCity in 1989 from the development studio Maxis. Will Wright, the lead developer and co-founder of Maxis, implemented various aspects of urban planning and computer modelling into SimCity, creating a complete city-building game that set the standard for the following titles. A SimCity game screenshot is presented in Figure 3.

Figure 3 A screenshot of the original SimCity.

After the commercial success of the original SimCity, new city-building games followed (within the SimCity series as well as titles from other development studios): SimCity 3000, SimCity 4, Tropico, CityLife etc. SimCity 2013 - the most recent title in the SimCity series - encountered several problems after its release, which led to the game's poor reception among players. In 2015, the Finnish game development studio Colossal Order released their take on a city-building game, named Cities: Skylines. This game was well received as it delivered desired features such as a 3D graphics environment, an extensive API for creating game modifications, a mass transit system, and well-functioning agent-based simulations controlling citizens, vehicles, and other game objects (Moss, 2015). Today, Cities: Skylines is arguably the best city-building game on the market. This can be concluded from (1) its commercial success, where Cities: Skylines has sold over six million copies (*Cities: Skylines Celebrates Fourth Anniversary and Six Million Copies Sold*, 2019) compared to SimCity 2013's two million copies (Matulef, 2013); and (2) the size of the gaming community gathered on forums on Reddit.com; the forum dedicated to Cities: Skyline has more than 300,000 subscribers (*R/CitiesSkylines*, 2019), whereas the forum dedicated to SimCity is followed by the much lower number of 25,000 subscribers (*R/SimCity*, 2019).

In Cities: Skylines, the player engages in urban planning by establishing the road network, controlling zoning, providing public services and public transportation, and taxation. The player maintains various elements of the virtual city such as its budget, education, employment, pollution levels, etc. The simulated phenomena can be monitored in the game's "info views" that provide visually attractive outputs (*Info Views*, 2019). Figure 4 presents an example of an info view displaying the noise pollution levels in the modelled city in Cities: Skylines. By comparing Figure 3 and Figure 4 it is clear that today's city-building games have improved significantly since the release of the original SimCity.

Figure 4 Example of a Cities: Skylines info view displaying the simulated noise pollution (*Info Views*, 2019).

4.3 City-building games as a learning tool in spatial planning classes

As mentioned above, games, in general, are attractive. Many researchers have concluded that it is the game's educational features that make playing them entertaining and thus attractive to players. Games provide a quantifiable outcome in the form of immediate feedback (Salen et al., 2004). According to Abt (1970), games provide a safe space for exploration and experimentation. These features allow the player to learn from the actions taken without the danger of any actual risk. A player progressing through challenges in the game's environment then experiences a feeling of satisfaction (Juul, 2013). This effect increases the learnability of the information presented by the game and because of that, games are considered to be an efficient learning tool (Gee, 2003; Prensky, 2003).

City-building games from the SimCity series have been implemented for the past three decades in numerous spatial planning classes (Adams, 1998; Gaber, 2007; Kim & Shin, 2016; Minnery & Searle, 2014; Terzano & Morckel, 2017). Adams (1998) concludes that the most important outcome of using SimCity in education is developing spatial-planning-like attitudes. Gaber (2007) considers the use of SimCity successful in specific learning objectives but warns us against thinking that such tool would serve as "a panacea that can save a poorly taught class". However, some researchers have pointed out major simplifications of the simulated urban processes in city-building games (Bereitschaft, 2016; Minnery & Searle, 2014). A realistic approach while using city-building games for the purpose of education should be taken for achieving sensible learning results. The instructor leading the class must be aware of the inaccuracies of the game and reflect on them rather than using the game as a dogmatic presentation of the topic being taught.

4.4 City-building games enabling participation in spatial planning

The majority of the world population now resides in urban areas and this trend will continue to grow due to an estimated 3 million of people migrating every day from rural areas to cities ("World Urban. Prospect. 2018 Revis.," 2019). At the same time, inhabitants of urban areas want to be more involved in the spatial planning processes which are, however, often too complex to comprehend. Therefore, there is a need to bridge the gap of data, information, and knowledge between the public and the processes of planning. One of the ways this can be achieved is through the use of games, which provide a means of playful participation in an attractive environment.

Numerous serious games have been used for participation projects, proving that the game approach is beneficial (Gordon et al., 2011; Gordon & Baldwin-Philippi, 2014; Poplin, 2014). Recently, commercial video games have started to be utilised for civic engagement as well. The technical and financial capabilities of the studios developing commercial video games are extensive (especially compared to serious games). Moreover, video game titles utilise gaming engines such as Unreal or Unity 3D that are at the forefront of progress in the visual graphics field. Therefore, commercial video games can often attract wider audiences. One of the games utilised for spatial planning is Minecraft. Minecraft has a large and active world-wide online community of over 100 million players. UN-Habitat saw the potential in the game's possibilities and its active community and has partnered with the creators of Minecraft, the development studio Mojang, to start a program called Block by Block. In this program, Minecraft is used to help with the redevelopment of selected areas. First, using geographical and satellite data, a model of the selected area is created within Minecraft. This base model is then presented to the surrounding community, whose members use, or rather play, the game to rebuild the modelled area according to their wishes. Finally, the resulting models are translated into plans for further implementation (UN Habitat, 2015). A similar participation project was done in the city of Exeter, England, where Minecraft was utilised for a design challenge of the town's historic centre (*Building a Sustainable Future with the Exeter 2025 Minecraft Challenge*, 2019). Recently, a case study in Brazil used Minecraft as a tool for engaging children in urban planning (de Andrade et al., 2020).

The game Cities: Skylines is built on the Unity 3D engine and thus offers a visually appealing environment in a spacious 3D world that can be roamed almost freely. In this game, the players usually build and manage imaginary cities. However, since this game allows building a city in great detail, many players started to model their hometowns or other well-known places in the world (*Amazingly Detailed Metropolises Recreated in Cities: Skylines – in Pictures.*, 2015). There have also been several case studies in which the game Cities: Skylines was used more professionally. The city of Hämeenlinna, in Finland, held a contest to design a new suburb near the city centre using the game Cities: Skylines. Players were given a base map of the city, which was prepared by the workers of the council, and then started building roads, buildings and services for the new suburb within the game (Brethonière, 2020; Guzman, 2016). The contest was open to players from all around the world and as such brought more diversity to the design ideas. On the other hand, Silvain Hamar de la Brethonière (2020) points out that international players lack a real connection to the modelled area and that participation projects should favour local citizens.

Another use of the game Cities: Skylines aimed to involve local citizens. In Stockholm, Sweden the game was used to model the intended development of the Royal Seaport district. The resulting model was then offered to the general public who could then explore the modelled area and contribute new ideas to the development plan (Andrew, 2016; *Video Game Cities Skylines Helps Plan Stockholm Development*, 2017). Figure 5 displays a communication among stakeholders in a participation project in Stockholm.

Figure 5 Cities: Skylines in a participation project in Stockholm (Borg, 2016).

4.5 City-building games as urban modelling tools: potential and limitations

City-building games represent a specific game genre due to their simulation of urban-related processes. Simulations in city building games often use similar models as modelling tools used in research: cellular automata, gravitational models, feedback loops (Prensky, 2001; Rufat & Ter Minassian, 2012). Cellular automata are also often used in video games, including Cities: Skylines, to simulate the behaviour of gasses, liquids, temperature, and electricity (vanden Broucke, 2017). The most used modelling tool in city-building games is the agent-based model that controls the behaviour of citizens, vehicles, and other game objects. These agents interact between each other independently of the mayor's (player's) actions, creating an artificial society where real-life phenomena emerge (Devisch et al., 2009). With the use of the agent-based model, the player could build a city that is close to the chaotic, unpredictable and self-organizing system defining modern cities (Portugali, 2000). An example of an interaction between agents controlling citizens and vehicles in Cities: Skylines can be seen in Figure 6.

Figure 6 Interaction of agents in Cities: Skylines (Info Views, 2019).

Rufat & Ter Minassian (2012) compared selected city-building games with modelling tools used in research. Rufat & Ter Minassian (2012) conclude that simulations in the city-building games are based on similar models to the ones used in research, but the main difference is in the ability to change the simulation parameters after observation and learning. Whereas scholarly modelling tools offer this feature, games do not. In other words, simulation logic in games is a "black box" – most often due to the protection of intellectual property - where the rules can be deduced only through exploration. This problem was also highlighted by Devisch (2008), who studied the possible use of SimCity in planning processes, and D'Artista & Hellweger (2007), who studied SimCity from the point of view of urban hydrology.

City-building games are also criticised for their simplification of urban processes. For example, the lack of mixed zone usage, a concept seen as beneficial among urbanists (Jabareen, 2006), was spotted in early versions of SimCity (Starr, 1994) and later in SimCity 4 and Cities: Skylines (Bereitschaft, 2016). City-building games are played from the position of an all-powerful mayor, though in reality, the planning processes involve many stakeholders (Bereitschaft, 2016; Haahtela, 2015). On the other hand, it is important to note that urban planning processes are complex, and as such cannot be conclusively modelled even with scholarly tools (Batty & Paul M. Torrens, 2001). Many simplifications are made due to our current inability to implement the full complexity of urban systems into the game. Nevertheless, some simplifications are incorporated into the games simply to enhance the playability of the game, thus making it more appealing to the player, a potential buyer (Dzieza, 2013; Fulton K., 2015).

4.6 Modifying the game through custom scripting

In general, the use of commercial video games in their original version for non-entertainment purposes is quite limited. However, these limitations, including the ones mentioned above, can be overcome or at least mitigated by incorporating changes to the game's behaviour. The process of changing the game using custom scripting is known in the gaming community as "modding" (Scacchi, 2010). This process can modify the original version of a video game to solve a given problem. Modding represents a way of accessing and changing the game's "black box" behaviour.

Most modern video games offer the possibility to change the game's behaviour through modding as this is a desired feature by the gaming community. However, the level of extensiveness and support of modding varies from game to game. Whereas in some cases the modding possibilities are quite limited, in other cases the game's behaviour can be changed significantly.

For example, the city-building game Cities: Skylines provides an extensive application programming interface (API) written in the programming language C# and modding support in form of online documentation and user forums. This feature is highly appreciated by the game's community; this is best documented by the large number of mods in existence: 175,970 created by the beginning of 2019 (*Cities: Skylines Celebrates Fourth Anniversary and Six Million Copies Sold*, 2019). Most of these mods are cosmetic additions to the game (e.g. a new type of tree) but some mods are professionally written modifications to the game's behaviour: changing the traffic management, allowing mixed zones, providing for the preservation of historic buildings, importing and exporting geographical data into the game, etc.

In a study done by Juraschek, Herrmann, & Thiede (2017), a model of the city Braunschweig, Germany was created using selected mods in the game Cities: Skylines to simulate the production of urban factories and evaluate various phenomena such as air pollution. A recent study implemented the game Cities: Skylines as a tool for simulating natural hazards in a university course for environmentalists (Fernández & Ceacero-Moreno, 2021).

The above studies implemented existing mods to modify the game to achieve the desired behaviour. The following studies went a step further and introduced the desired behaviour by developing a new game mod. Olszewski, Cegiełka, Szczepankowska & Wesołowski (2020) in their study programmed a mod for importing topographic data stored in CityGML format. The created model was then used for developing a serious game within the toolset environment of Cities: Skylines. Eisele, Mardari, Dubey, & Karsai (2017) implemented significant modifications to the game Cities: Skylines in order to simulate decentralized smart traffic systems. The team at the KAUST university lead by Shehab Ahmed (personal communication, July 28, 2020) is using a modified version of Cities: Skylines to conduct real-time traffic and energy consumption simulations in modelled cities.

5. SELECTION OF A CITY-BUILDING GAME WITH THE HIGHEST POTENTIAL FOR ITS APPLICATION IN SPATIAL PLANNING

In order to achieve the research goals of this thesis, a suitable game had to be selected first. Given that the focus of this work is on spatial planning, games that enable a player to build and manage a city were preferred. The best options to consider were commercial video games with modding capabilities. These types of games are highly attractive, supported by large development studios and, thanks to the modding capabilities, offer the possibility to modify the game's behaviour to fit the purpose of the study (Pinos, 2019).

There are numerous city-building games to choose from. However, not all games can be efficiently used for the purposes of spatial planning. The following uses of a city-building game were considered for the selection:

- As an urban modelling tool
- As a visualisation tool
- As a tool facilitating civic engagement

5.1 Evaluation criteria

The selection of the game was based on several aspects. First, the selected game had to be attractive and relevant to today's players. The attractivity of a game in this regard is not understood as a visual attractivity but rather how the game is perceived by the wider gaming community. It is assumed that a game which is attractive to a large number of players has a certain level of quality and does not include any critical issues preventing its sensible use. In this case, the number of copies sold and the number of subscribers to a user forum dedicated to the game were considered as indicators of the game's attractivity. Next, the selected game had to offer a sufficient graphics environment so that a real-world place can be representatively recreated within the game (e.g. the game should offer a 3D environment). Furthermore, the selected game must provide extensive modding capabilities, which enable modifications to the game's looks and behaviour. In addition to the programming interface, the game should offer sufficient documentation and support for the modding environment. Last, the selected game must represent city related processes and optimally will have previously been used in a spatial planning. The above aspects were represented in the following criteria used for evaluating the game selection:

- Attractivity (in number of copies sold)

- Attractivity (in number of subscribers of the user forum dedicated to the game)
- Provides city-related simulations
- Previous uses in spatial planning
- Provides 3D space representation
- Provides a modding environment
- Provides modding support
- Enables geodata processing

5.2 Evaluated games

Evaluation of all commercial games with a focus on city-building which are available on the market was outside of the scope of this research. Therefore, the following games were pre-selected for evaluation based on the author's own experience:

- Minecraft
- Cities in Motion 2
- Cities: Skylines
- SimCity 2013

Minecraft

Minecraft was developed by Marcus Persson and released by Mojang in 2011. Even ten years after its release, this game is very popular. As of today, Minecraft is the best-selling video game of all time, selling over 180 million copies across all platforms. Minecraft is often referred to as "digital Lego" where the players can build almost anything from blocks of 1x1x1 metres. In addition to the original version, Minecraft also offers specialized editions such as the Educational Edition. Thanks to that, Minecraft has been used increasingly for education (Bourdeau et al., 2021; Demirkiran & Tansu Hocanin, 2021). Due to its environment offering near-unlimited creativity, Minecraft have been used for numerous visualisations of real-world places and participation projects involving spatial planning (*Building a Sustainable Future with the Exeter 2025 Minecraft Challenge*, 2019; UN Habitat, 2015). On the other hand, this game is not considered to be a standard city-building game as it does not offer any city-related simulations in the "out-of-the-box" version of the game. Any desired city-related processes must be programmed into the game using Minecraft's extensive modding environment. The modding environment consists of an API written in Java, several 3rd party tools for processing data for Minecraft, online documentation and user forums. Figure 7 shows an example of using Minecraft for a participation project (Scholten et al., 2017).

Figure 7 Building in Geocraft (a modified version of Minecraft) generated from a Digital Surface Model. Detail added by participants (Scholten et al., 2017).

Cities in Motion 2

Cities in Motion 2 was developed by Colossal Order and released by Paradox in 2013. It is a business simulation game with a focus on transportation and traffic simulations. The goal of the game is to implement and improve a public transport system in a prebuilt city. The player can choose from several major cities of the world. Due to its very narrow specialization, the gaming community is small. Cities in Motion 2 offers a modding environment, but the official modding documentation is sparse. Furthermore, the size of the gaming community affects the number of created mods, custom assets, and advice from experienced players. There are no known uses of this game in spatial planning. Figure 8 shows an example of public transport management in the game Cities in Motion 2.

Figure 8 Managing public transport in Cities in Motion 2.

Cities: Skylines

Cities: Skylines is a city-building game developed by Colossal Order and published by Paradox in 2015. In this game, players plan, build, and manage a virtual city as an all-powerful mayor. Players engage in urban planning by controlling zoning, road placement, taxation, public services, etc. The game uses an agent-based model to simulate up to one million unique citizens and their daily routines. Within the city-building game genre, Cities: Skylines is currently the best-selling title, with 6 million copies sold by 2019 (*Cities: Skylines Celebrates Fourth Anniversary and Six Million Copies Sold*, 2019). This game provides a 3D graphic environment in which real-world places can be recreated with high accuracy. Cities: Skylines has previously been used for the purposes of spatial planning (Andrew, 2016; Guzman, 2016; Juraschek et al., 2017). The game provides an extensive modding environment consisting of an API written in C#, online documentation, and user forums. Figure 9 shows an example of managing a city in the game Cities: Skylines.

Figure 9 Managing a city in Cities: Skylines (*Info Views*, 2019).

SimCity 2013

SimCity 2013 is the latest title from the well-known SimCity series. It was developed by Maxis and published by Electronic Arts in 2013. SimCity 2013 is in many ways a standard city-building game, with one major difference: a multiplayer mode. Nevertheless, this feature as well as the game as a whole has been criticised by both players and game reviewers. Despite this, the game was commercially successful, selling over 2 million copies world-wide (Matulef, 2013). Although this game provides a modding environment, numerous players have characterised it as faulty and limited. SimCity 2013 has been used in spatial planning; however, only in educational settings (Terzano & Morckel, 2017). The use of this game for other purposes, such as visualisation, is limited. Figure 10 shows an example of managing a city in the game SimCity 2013.

Figure 10 Managing a city in SimCity 2013.

5.3 Evaluation table

Pre-selected games were evaluated against the chosen criteria in Table 1. The criterion *Copies sold* represents the total number of copies sold in millions. The criterion *Community* represents the number of subscribers on the Reddit.com subforums dedicated to each game (e.g. reddit.com/r/Minecraft) in thousands. The following criteria are recorded as a Yes/No option. The criterion *Urban simulations* states whether the game offers out-of-the-box simulations of city-related processes. The criterion *Previous uses* states whether the game has been used previously for purposes of urban planning. The criterion *3D space* states whether the game offers a 3D graphics environment. The criterion *Modding environment* states whether the game offers tools to modify the game. The criterion *Modding support* states whether the game offers learning material and support for creating custom game modifications. The criterion *Geodata processing* states whether the game offers tools for processing geographical data (e.g. data import). Game names were shortened as follows: Cities in Motion 2 (CiM 2), Cities: Skylines (C: S), SimCity 2013 (SimCity).

Table 1 Evaluation table of the pre-selected games.

Games	Minecraft	CiM	C: S	SimCity
Copies sold	180	1	6	2
Community	2500	1.2	273	25.9
Urban simulations	No	Yes *	Yes	Yes
Previous uses	Yes	No	Yes	Yes **
3D space	Yes	Yes	Yes	Yes
Modding environment	Yes	Yes	Yes	Yes
Modding support	Yes	No	Yes	No
Geodata processing	Yes ***	No	Yes ***	No

** only traffic and transportation simulations*

*** only education using imaginary cities*

**** combination of inbuilt and 3rd party tools*

As the numbers suggest, Minecraft is the most attractive game in the evaluation. It also has been used previously in spatial planning for visualisations. But other uses are quite limited as Minecraft does not offer out-of-the-box city-related simulations.

The potential of SimCity 2013 for its application in spatial planning is heavily limited by an insufficient modding environment. Particularly, the lack of modding documentation and support makes the development of geodata processing tools very difficult.

Cities in Motion 2 scored the worst; however, due to its specialised focus on transport and traffic management, building a model of a real-world place may be worth exploring.

Cities: Skylines achieved the highest score. Though the numbers of players and copies purchased is not as impressive as in the case of Minecraft, it is still the best-selling game in the city-building genre. Cities: Skylines provides a well-supported modding environment, enabling the development of geodata processing tools. This game can be used in all intended purposes of spatial planning. **Therefore, the game Cities: Skylines was selected as the game with highest potential for application in spatial planning.**

6. DEVELOPMENT OF GEODATA PROCESSING METHODS AND TOOLS FOR GAME WORLD CREATION

Although city-building games usually operate in imaginary spaces, many players have used them to manually create models of various places on Earth. Nevertheless, the accuracy of such models is often insufficient and the creation process time consuming. This is confirmed by Juraschek et al. (2017) who stated in their research that "as for now no automated script for transferring the topological data into the game is available that produces high quality results. This can make the creation of the model very time consuming in the beginning." Since 2017, a few mods have been created to process geographical data for the game Cities: Skylines. But these mods work only with OSM road data and include limited options for pre-processing the data. Therefore, methods for pre-processing geodata as well as a tool for importing the pre-processed data into the game were developed as part of Objective 2.

The game Cities: Skylines offers an extensive API that can be used to modify the original version of the game. Using this API, written in the programming language C#, a game mod, named GeoSkylines, was developed for generating game objects from pre-processed geographical data (Pinos et al., 2020). GeoSkylines is available on the platform Steam, where it is currently subscribed to by 285 users (Pinos, 2020b). The source code and full documentation is available on GitHub (Pinos, 2020a) and is also included as appendix 1.

6.1 File structure of the GeoSkylines mod

The GeoSkylines mod is split into several C# files.

GeoSkylines.cs

Defines short and long description of this mod that is visible in the game's content management menu.

GeoSkylinesLoading.cs

Defines several classes such as GeoSkylinesNode for managing geographical data.

GeoSkylinesThreading.cs

Defines the class GeoSkylinesThreading that inherits from the API's class ThreadingExtensionBase. By overriding the method OnUpdate(), the geodata processing methods can be triggered by an input, most commonly a combination of keys.

GeoSkylinesImport.cs

Defines the GeoSkylinesImport class and its methods for generating game objects from geographical data, such as ImportRoads().

GeoSkylinesExport.cs

Defines the GeoSkylinesExport class and its methods for exporting game objects as geographical data (e.g. road segments).

WGS84_UTM.cs

Defines the UTMResult class and its methods for converting coordinates between the coordinate systems World Geodetic System (WGS) 84 and Universal Transverse Mercator (UTM).

Additionally, the library burningmime.curves has been added into the GeoSkylines mod. This library defines methods for creating Bezier curves that are used for importing roads into the game.

The mod is distributed as a compiled Dynamic Link Library (DLL) file.

6.2 Geographical data input format and pre-processing

Since the game does not work with common GIS data formats, the easiest way to upload the geodata was to use a CSV file with geometry recorded in a WKT format. WGS84 was selected as a default coordinate system for storing geodata. Geodata were collected from freely available sources, predominantly from OSM. OSM data were downloaded using QGIS and the QuickOSM plugin. Another QGIS plugin, HCMGIS, provides a selection of base maps that help with navigating to the area intended for modelling. Figure 11 shows downloaded OSM roads (tag *highway*) using the QuickOSM plugin for the Olomouc area (specified simply by the canvas extent).

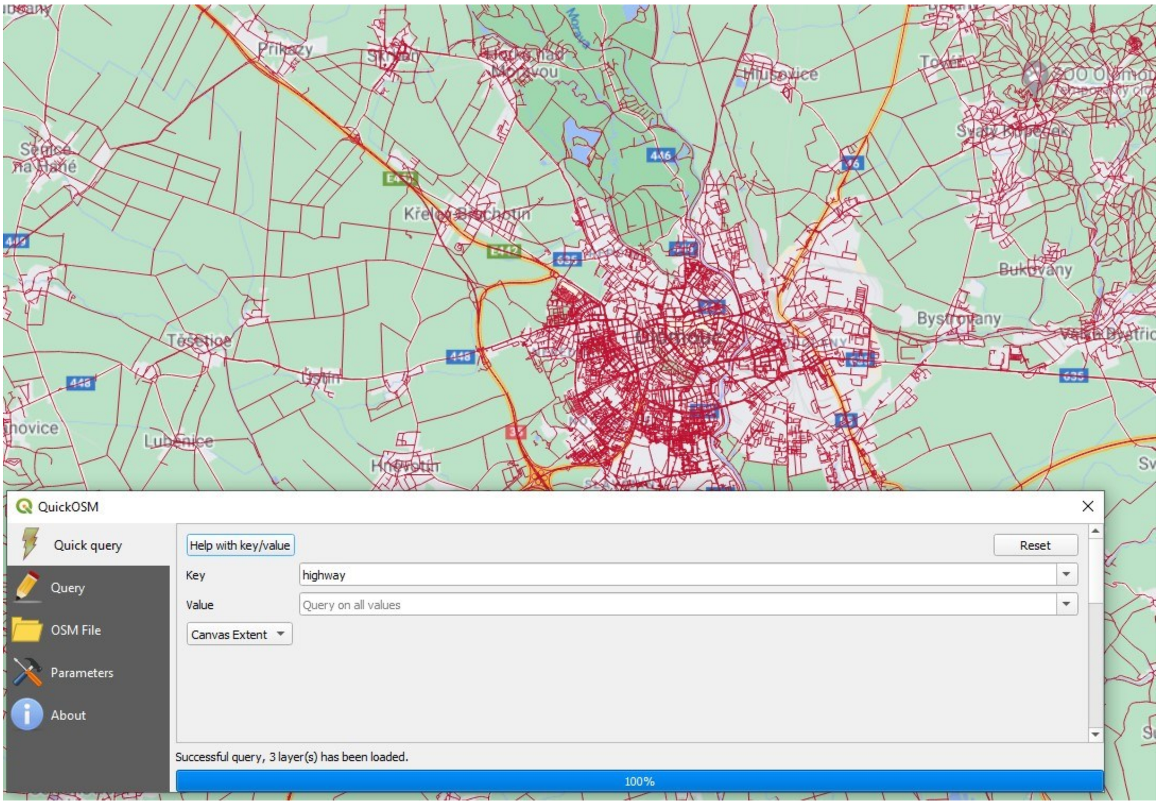

Figure 11 Vector layer of OSM roads downloaded with QGIS' plugin QuickOSM.

The downloaded OSM data are stored only temporarily in the computer's memory and thus must be exported as permanent CSV files. The import methods of the GeoSkylines mod require specific fields (columns) to be present in the CSV files such as road_name, road_type etc. for creating the game objects. Renaming fields or deleting unnecessary fields can be done in MS Excel or Notepad.

The naming convention for the CSV files for import is "<object_name>_rwo.csv" (e.g. roads_rwo.csv). The naming convention for the exported CSV files is "<object_name>_cs.rwo". The CSV files are loaded from the game's default folder (usually c:\Program Files (x86)\Steam\steamapps\common\Cities_Skylines\Files\). This folder also contains CSV files for matching geodata types with game object types (e.g. types of roads) and a configuration file import_export.txt. An example of the CSV files and a configuration file is displayed in Figure 12.

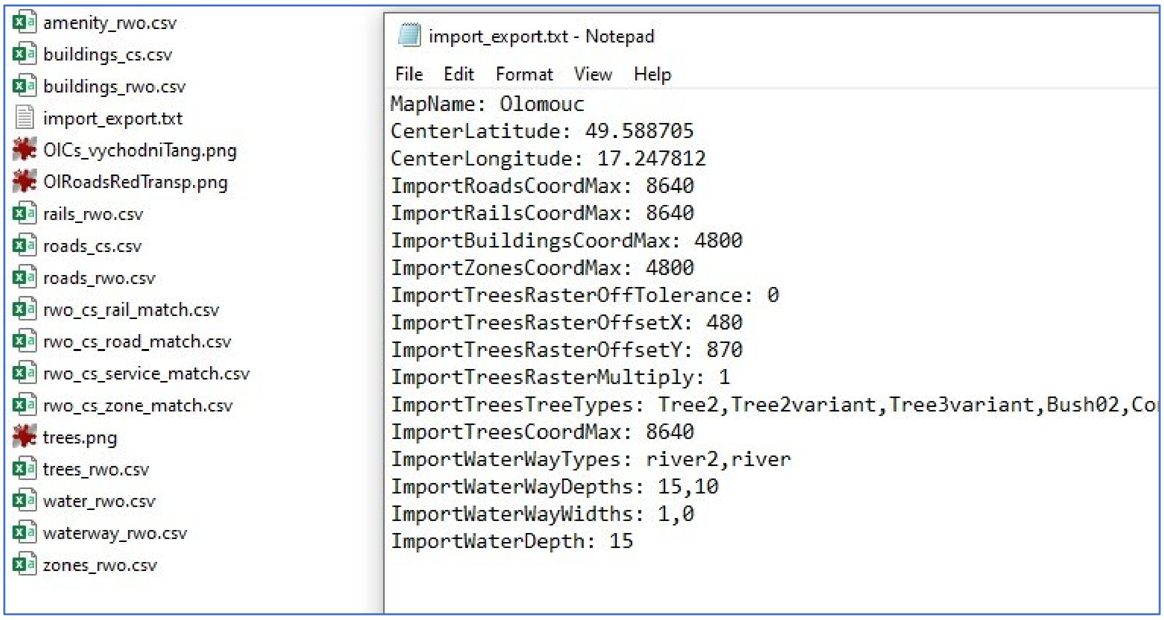

Figure 12 CSV files and a configuration file for the GeoSkylines game mod.

The configuration file import_export.txt contains numerous parameters, in the format of parameter_name: parameter_value, which are used by the methods of the GeoSkylines game mod. Parameter MapName serves only an orientational purpose. The most important parameters are CenterLatitude and CenterLongitude, which are used for converting geographical coordinates to game coordinates and vice versa.

6.3 Conversion of coordinates

The game Cities: Skylines utilises a projected coordinate system using metres as units in a game area of 17.28 km x 17.28 km. This coordinate system has three axes: x, y and z. The axis y, contrary to the geographical standards, stores height values (behaviour inherited from the gaming engine Unity 3D). Axis x serves as 'easting' and axis z serves as 'northing'. The point of origin is in the centre of the game area and the axes x and z range from -8640 to 8640. The game's coordinate system can be considered as a variation of the UTM projected coordinate system. Thus, for the coordinate conversion, a standard algorithm for converting WGS 84 coordinates to UTM coordinates was used, and then the UTM coordinates were recalculated to the game coordinates. The full conversion process is documented in the following schema shown in Figure 13.

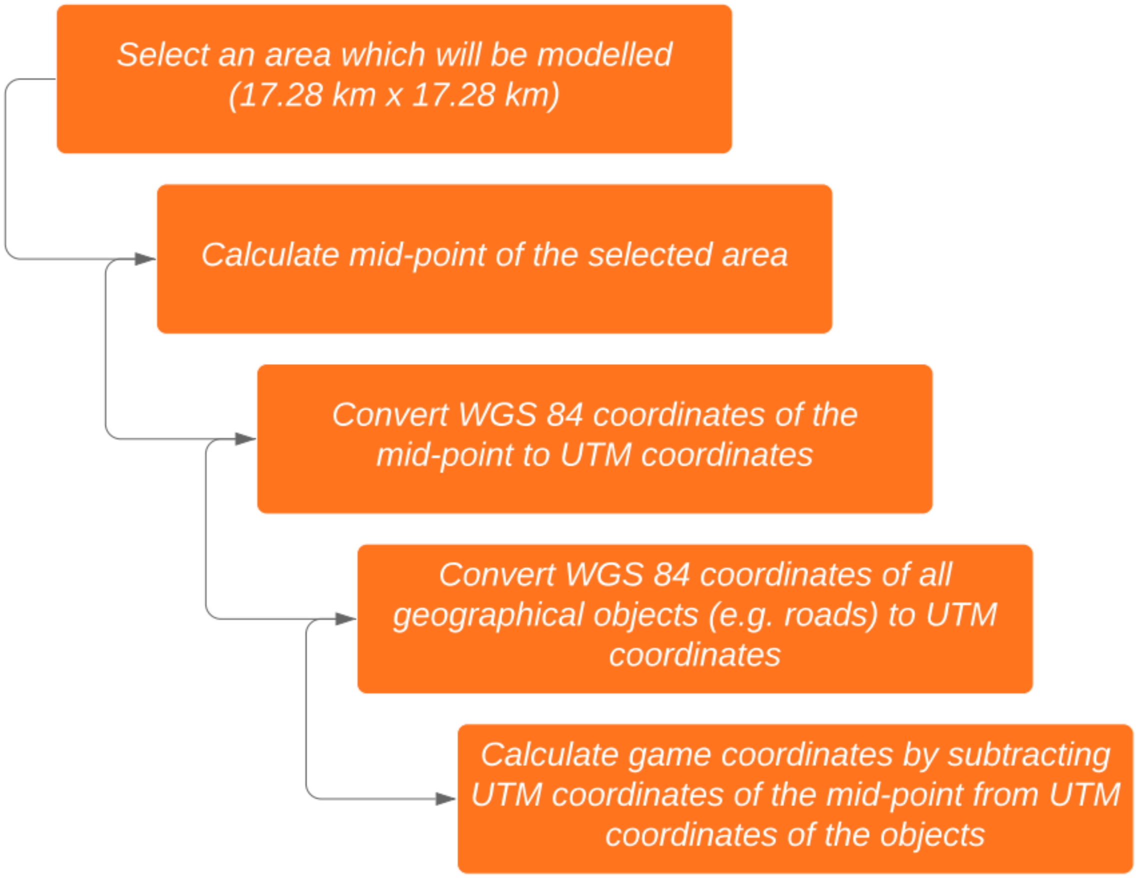

Figure 13 Schema of the conversion of geographical coordinates to game coordinates.

Coordinates of the game object are calculated according to formulas 1 and 2:

$$X = E_O - E_M \qquad (1)$$

$$Z = N_O - N_M \qquad (2)$$

Where X and Z represent the game axes in 2D space, E represents easting, N represents northing, O represents the geographical object and M represents the mid-point.

Likewise, the full conversion process for export includes following steps:

- Convert WGS 84 coordinates of the mid-point to UTM coordinates
- Calculate UTM coordinates of the game objects according to formulas 3 and 4:

$$E_O = X + E_M \qquad (3)$$

$$N_O = Z + N_M \qquad (4)$$

- Convert UTM coordinates of game objects to WGS 84 coordinates (the required UTM zone is obtained from the UTM coordinates of the mid-point).

6.4 GeoSkylines import methods

The main functionality of the GeoSkylines game mod is due to its import methods, which generate game objects based on the loaded geographical data. Using these methods, a road and rail network can be generated, as well as water basins and tree coverage. GeoSkylines import methods are activated in the game via hot key combinations. Table 2 displays the full list of import methods of the GeoSkylines game mod.

Table 2 List of import methods of the GeoSkylines game mod

Method name	Method description	Hot key	Requires
ImportRoads()	Uploads roads_rwo.csv, matches road types according to rwo_cs_road_match.csv and creates a road network.	Right Ctrl + R	roads_rwo.csv, rwo_cs_road_match.csv, import_export.txt
ImportRoadNames()	Intended for updating road names of manually constructed roads.	Right Ctrl + M	roads_rwo.csv Import_export.txt
ImportRails()	Uploads rails_rwo.csv, matches rail types according to rwo_cs_rail_match.csv and creates a rail network.	Right Ctrl + L	rails_rwo.csv, rwo_cs_rail_match.csv, import_export.txt
ImportWaterReservoirs()	Uploads water_rwo.csv and lowers the terrain for each polygon using the Ray casting algorithm.	Right Ctrl + W	water_rwo.csv, import_export.txt
ImportWaterWay()	Uploads waterway_rwo.csv and lowers the terrain for each waterway segment.	Right Ctrl + Q	waterway_rwo.csv, import_export.txt
ImportTreesRaster()	Uploads trees.png and for every non-white pixel creates a tree.	Right Ctrl + T	trees.png (1081 x 1081 resolution), import_export.txt
ImportTreesVector()	Uploads trees_rwo.csv and creates a tree for each record.	Right Ctrl + V	trees_rwo.csv, import_export.txt
ImportZones()	Uploads zones_rwo.csv, matches locations of each zone with the locations of game's zone blocks and sets the zone.	Right Ctrl + Z	zones_rwo.csv, rwo_cs_zone_match.csv, import_export.txt

ImportServices()	Uploads amenity_rwo.csv, matches service types according to rwo_cs_service_match.csv and creates services.	Right Ctrl + S	amenity_rwo.csv, rwo_cs_service_match.csv, import_export.txt

6.5 GeoSkylines export methods

The newly developed game mod GeoSkylines also provides methods for exporting game objects, specifically trees, roads, railways, buildings, and zoning into a GIS format that could then be further processed. GeoSkylines export methods are activated in the game via hot key combinations. Table 3 displays the full list of export methods of the GeoSkylines game mod.

Table 3 List of export methods of the GeoSkylines game mod.

Method name	**Method description**	**Hot Key**	**Requires**
ExportSegments()	Exports all road segments created in the game into a CSV file.	Right Ctrl + G	import_export.txt
ExportBuildings()	Export all buildings created in the game into a CSV file.	Right Ctrl + H	import_export.txt
ExportZones()	Exports all zones created in the game into a CSV file.	Right Ctrl + J	import_export.txt
ExportTrees()	Exports all trees created in the game into a CSV file.	Right Ctrl + K	import_export.txt

Figure 14 shows exported roads and buildings in QGIS. Purple lines represent game roads and grey polygons represent game buildings. Exported data are displayed on top of a base map layer in the location of the city of Svit (Slovakia), which confirms the accuracy of the algorithms used for converting coordinates. Additionally, as visible in Figure 14, the Bezier curve algorithm was employed to efficiently export curved roads created within the game.

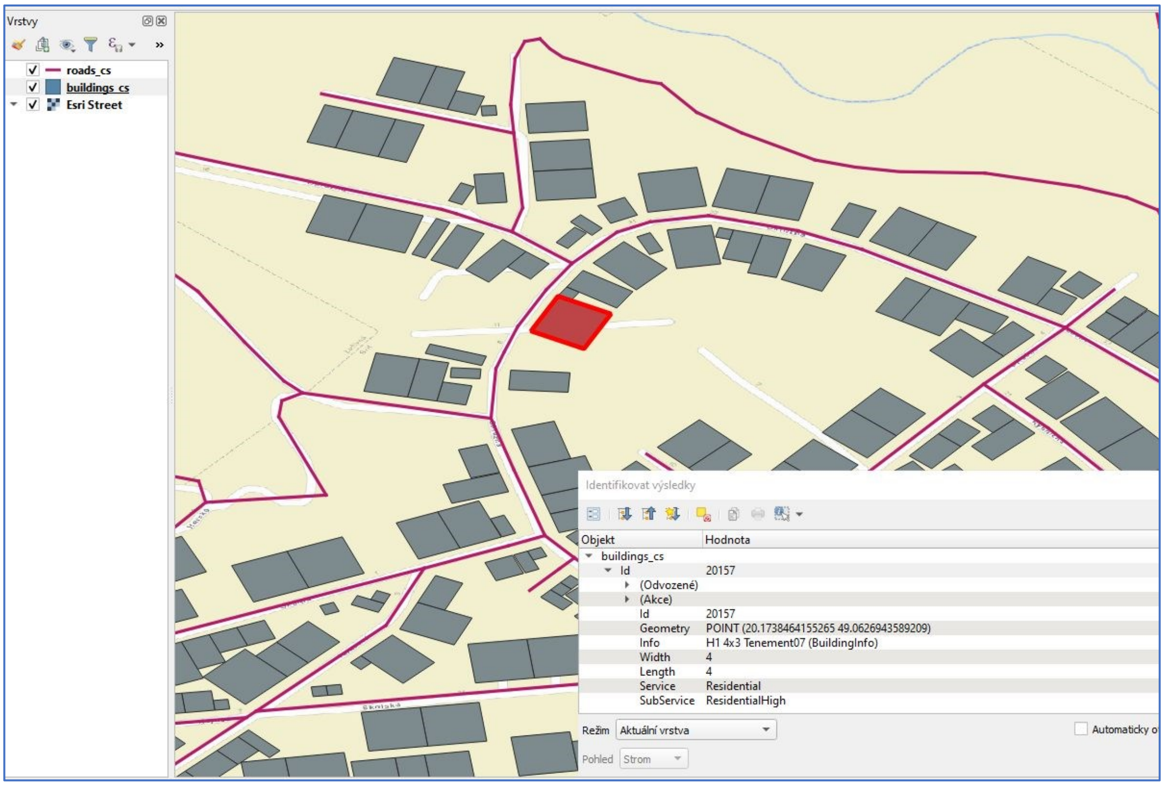

Figure 14 Game roads (purple) and game buildings (grey) exported as CSV files and displayed in QGIS. Characteristics of the selected game building are displayed in the attribute viewer. A base map layer was added for geospatial context.

6.6 GeoSkylines helper methods

The GeoSkylines game mod also includes two helper methods, most notably method OutputPrefabInfo(), which exports the names of all types of the game objects available in the installed version of Cities: Skylines. The exported list can vary greatly based on installed Downloadable Content (DLC) and custom assets. The information obtained from this method helps construct the matching files, where types of geographical objects are matched with types of game objects. Table 4 displays the list of helper methods of the GeoSkylines game mod.

Table 4 . List of helper methods of the GeoSkylines game mod.

Method name	Method description	Hot Key	Requires
DisplayLLOnMouseClick()	Displays screen, game and WGS 84 coordinates of the location clicked.	Right Ctrl + left mouse click	import_export.txt
OutputPrefabInfo()	Outputs all road, building and tree types that are currently loaded in the game.	Right Ctrl + P	nothing

6.7 Challenges and algorithmic solutions

The ideal goal was to create a tool that, based on the geographical data, would generate a near usable game model. However, during the development and testing of the GeoSkylines mod numerous challenges were encountered; some were successfully resolved while others, mainly due to their complexity, were left unresolved. The following text highlights the most notable examples of the challenges encountered.

6.7.1 Importing roads

The road network is the backbone of any model created in Cities: Skylines. Along the road are automatically created zone blocks, where – after zoning – buildings are constructed. Roads and paths serve as links for agents (cars, cyclists, and pedestrians) to move around the model. Therefore, most of the focus while developing the GeoSkylines mod was given to the method ImportRoads().

The first challenge was to prevent multiple creations of a game segment node (class type NetNode) for the same geographical location. This was resolved by creating a dictionary object where the ID of a NetNode is stored against its location (the game coordinates). Before creating a new node, the program checks whether a node already exists at this location.

Even at the early stages of the development, the method ImportRoads() was capable of generating a topologically connected and therefore functional road network. However, this road network included several issues that required further attention. The main issues were:

A. Some geographical roads (especially curves) were represented as multiple short narrow segments, thus generating an unnecessary high number of game nodes and segments. Because of this issue, the game's limit of nodes and segments could be exceeded. Additionally, multiple short segments close to each other generate graphic glitches (example shown in Figure 15).
B. Geographical roads represented by very long lines. Roads with an excessively long segment generate graphic glitches.
C. Generating game roads from 2D geographical data resulted in all overpass roads laying flat on the ground (or on top of other roads).

Figure 15 An extreme example of a badly imported roundabout.

Issue A was successfully resolved by implementing Bézier curves. Mortenson (1999) defines a Bézier curve as „a parametric curve used in computer graphics and related fields". For implementing Bézier curves in the GeoSkylines mod, the C# library burningmime/curves was selected (*Bézier Curves from Burningmime*, 2015). Using this library, a list of vertices representing planar coordinates (in this case of a node), can be transformed into a Bézier curve by calling:

```
CubicBezier[] curves = CurveFit.Fit(nodes, 8);
```

The algorithm then calculates necessary parameters from the curve and uses them for generating a game's road segment (including start and end nodes). Contrary to the library's documentation, the suggestion to reduce the number of vertices using a Ramer-Douglas-Peucker algorithm was not followed. Every vertex co-defines the shape of the road; if any vertex was removed due to a reduction algorithm, the shape of the road would change.

Though Bézier curves are, as the name suggests, ideal for generating curved segments, this solution was applied even for segments with a minimum curvature (except for simple segments defined by only start and end vertices). However, transforming most of the segments into curves removed junctions from the resulting network model thus making it unusable. To fix this issue, the program was updated to search for nodes with multiple segments connecting to it and mark it as a junction. The curves were then created only between a start node and a junction and another one between a junction and an end node. Figure 16 A shows an example of a road network with roads represented by segments and nodes. Figure 16 B shows in red start and end nodes as well as detected junction nodes. These nodes will be recreated in the game and curves will be created in between them. The remaining nodes (in blue) will not be recreated. This solution minimizes the node and segment creation, which helps avoid exceeding the game's limits. Additionally, these created curves successfully remove graphic glitches.

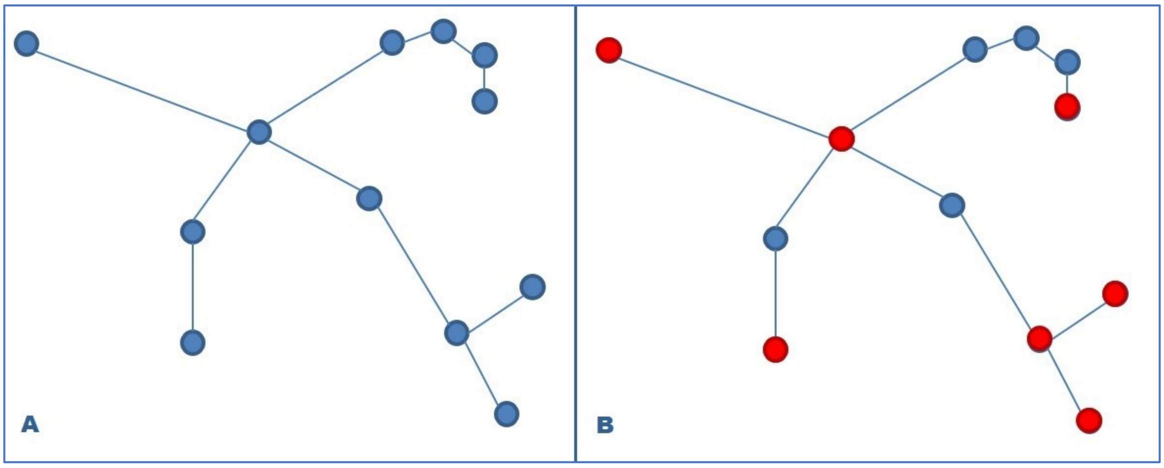

Figure 16 Pre-processing of the road network. A: Initial state of the road network represented by segments and nodes. B: curves are generated from roads between the red points (start, end and junction nodes).

In order to resolve issue B – roads represented by excessively long line geometries – the game's segments length limit had to be tested first. It was found that in Cities: Skylines, the length limit of a segment is around 120 metres. Longer segments (generated by code) start to produce graphic glitches. Therefore, a splitting mechanism was added to the ImportRoads() method to prevent this issue.

Unfortunately, not all issues could be resolved successfully. This was the case of issue C – no elevation for overpass roads. In general, OSM data do not store z values in the record's geometry. For roads, relative z value can be obtained from the tag *layer*, which signifies whether a road is crossing another object (road, river, path). Several attempts were made to utilize the information in the tag *layer* to introduce an elevation to the generated game roads. However, the results were unsatisfying, partly due to code insufficiency and partly due to data inaccuracy, and thus not implemented permanently to the GeoSkylines mod.

6.7.2 Importing trees

For importing trees, GeoSkylines mod offers two methods: ImportTreesVector() and ImportTreesRaster(). The method ImportTreesVector() creates tree coverage in the game from a CSV file with point geometries. This method presents the fastest solution in case a tree layer with point geometries is available. However, polygon layers specifying areas of greenery (e.g. Urban Atlas Street Tree layer) are more common. In this case, a geoprocessing method should be used to generate points within polygons (e.g. Regular points function in QGIS).

The method ImportTreesRaster() creates tree coverage from a provided PNG file of resolution 1081 x 1081 pixels (one pixel represents 16 metres). For this method a raster tree layer can be used or a PNG image for the modelled area can be generated from a GIS software. The method then loops over each pixel and generates a tree for every non-white pixel found. A randomness was added while calculating coordinates for the game trees to prevent a gridded look for the generated tree coverage. Another added mechanism is the option to multiply or reduce the number of the generated trees (e.g. to avoid reaching the game's limit 250 000 of trees) by specifying the parameter *ImportTreesRasterMultiply* in the configuration file import_export.txt. This parameter, defined as a number, specifies a step at which tree creation will be skipped (if number is negative) or an additional tree will be created (if number is positive).

Using the parameter *ImportTreesTreeTypes*, the user can specify what types of trees will be generated (to find out what tree types are loaded in the game, the use of the method OutputPrefabInfo() is recommended). Both methods for importing trees work with this parameter. Tree types are selected at random from the defined list.

6.7.3 Importing water basins

Water objects such as rivers or lakes are not represented in Cities: Skylines as discrete objects and thus cannot be generated in a similar way like roads or trees. However, using the TerrainManager class, it is possible to adjust the height of a specified location in the game area. The height information is stored for each cell of a 1081 x 1081 grid which represents the whole game area. When a new height is calculated, the terrain then can be updated by calling the API code:

```
TerrainManager.instance.RawHeights[anIndex] = newHeight;

TerrainModify.UpdateArea(gridX - 2, gridZ - 2, gridX + 2, gridZ + 2, true,
true, false);
```

First, the X and Z game coordinates must be recalculated to the 1081 x 1081 grid. Then, using the new coordinates, an index that identifies the specific location in the height grid is calculated (gridZ * 1081 + gridX). Height values are stored as bytes of a 16-bit unsigned integer. The game's height range, 0 – 1024 metres, is therefore represented by the byte range 0 – 65535. Using the parameter *impWaterWayDepths* from the configuration file import_export.txt, the depth in metres of a waterway can be defined. The defined depth is recalculated to bytes and then simply deducted from the current height of a specific location. Finally, the API's method UpdateArea() updates the game's terrain to reflect the new height.

Geographical vector data are defined by a vector of X and Y coordinates. Just adjusting the height in the geometry's vertices would not be enough to create a water basin. Thus GeoSkylines' method ImportWaterWay() includes a mechanism for creating additional points every 5 metres between the start and the end vertices of a segment. In the case of water bodies that are defined by polygon geometries, additional points must be created not just in between vertices but also inside the polygon. To achieve this functionality, method ImportWaterReservoirs() first creates a bounding box around the polygon geometry and then, starting from left bottom corner (X_{min} and Z_{min}), adds a point every 5 metres. Every point is then tested using a method IsPointInPolygon(Vector2[] polygon, Vector2 point). If the point is within the polygon, then similar calculations to those that are described above to obtain a new height are applied. Method IsPointInPolygon() is based on a ray casting algorithm that projects a ray from a given point and calculates how many times the ray intersects the edges of the polygon. For points inside the polygon, the ray intersects the polygon an odd number of times. Figure 17 A shows a set of vertices of a polygon – the initial state of the calculations. Figure 17 B shows a bounding box created around the original polygon and a pair of example points where a filled point is within the polygon (a ray cast from this point intersects the polygon one time) and an empty point is outside of the polygon (a ray cast from this point intersects the polygon twice).

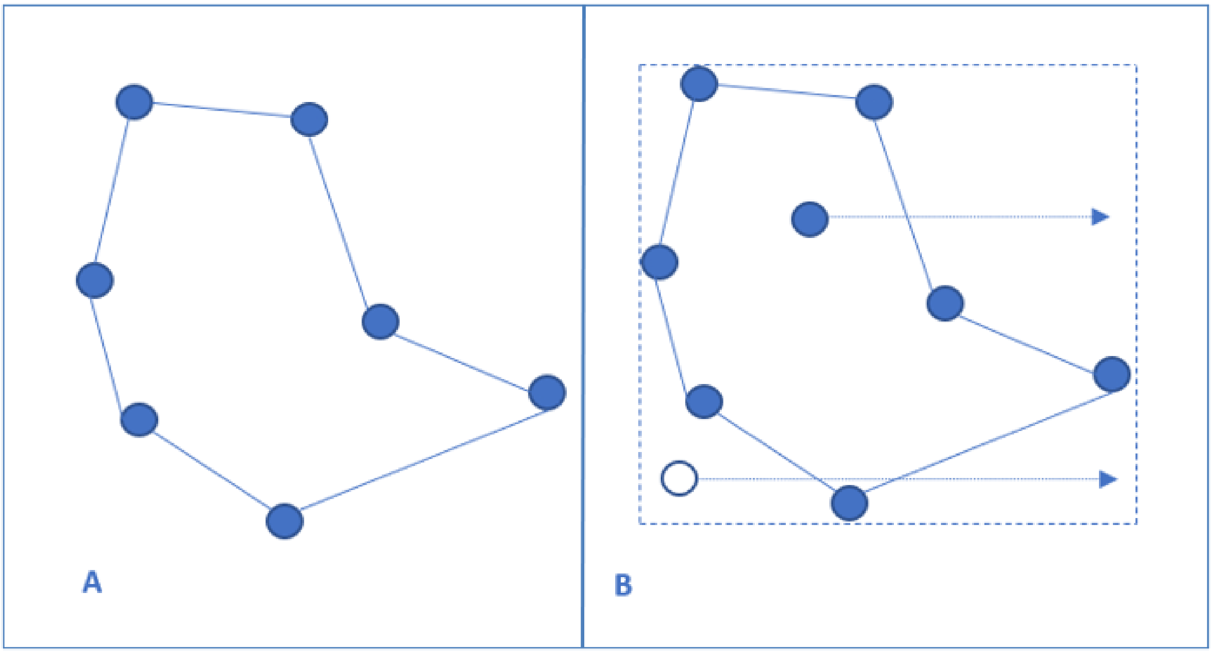

Figure 17 Searching for points within a polygon using the ray casting algorithm.

6.8 GeoSkylines mod summary

The GeoSkylines mod consists of approximately 4000 lines of code written in the programming language C#. This mod offers 15 callable methods (9 import, 4 export and 2 helper methods) that create game roads, railways, trees, water basins, services and zoning based on the source geographical data, or export game roads, railways, buildings, trees and zones as geographical data.

In contrast to other available Cities: Skylines mods that work with geographical data, the GeoSkylines mod requires pre-processing of the geographical data and thus is less immediately user-friendly. However, on the other hand, this mod offers a much wider range of options in regards to data processing and the number of game objects that can be created.

The GeoSkylines mod was published on the platform Steam Workshop. The mod can be installed into Cities: Skylines by subscribing to it on Steam Workshop. At the moment, 291 users are subscribed to the mod GeoSkylines (Pinos, 2020b). Alternatively, the mod's DLL file can be directly added to the game's addons folder. The DLL, the complete source code and the step-by-step documentation is available on GitHub (Pinos, 2020a) and is also included as appendix 1.

7. CREATION OF MODELS IN A SELECTED CITY-BUILDING GAME

This section describes the process of creating models of the cities Svit (Slovakia) and Olomouc (Czech Republic) in the game Cities: Skylines. The creation of a model is in this text distinguished into two stages:

- Generating a base model using GeoSkylines import methods
- Manual post-processing of the base model into a final, playable model

Initially, the city of Svit was selected for this research because this city has a population of only 7,790 inhabitants and is relatively young and thus would contrast with the city of Olomouc. However, in the end, the model of Svit was not used for any case study and was predominantly used for testing of the GeoSkylines methods. In the case of the city of Olomouc, first a base model was generated and then this model was further processed into two playable models of Olomouc that will be described below.

7.1 Creation of the Svit base model

The city of Svit is relatively small and is located in a rural area. The mid-point of the modelled area was set to:

- CenterLatitude: 49.063148
- CenterLongitude: 20.185709

The selected mid-point was then used to calculate a geographical bounding box of 17.28 km x 17.28 km, representing the size of the Cities: Skylines game area. Next, the following geographical datasets were obtained for the Svit area:

- PNG heightmap from the external tool Terrain.party. Instead of using an in-built map box only restricted to a 17 km × 17 km area, the following request to the Terrain.party's API with exact coordinates was called:
    - http://terrain.party/api/export?name=Svit&box=20.311757266359,49.1351685440791,20.060024494391,48.9909768926872
- Road vector layer from OSM (tag highway). This layer was converted to the file roads_rwo.csv.
- Waterway layer from OSM (tag waterway). This layer was converted to the file waterway_rwo.csv.

- Water body layer from OSM (tag natural=water). This layer was converted to the file water_rwo.csv.
- PNG image of tree coverage from a CORINE land cover layer. This layer was clipped according to the defined area and filtered to include only forested areas (codes 311, 312, 313).

After preparing the geographical datasets and copying them to the designated folder, the following steps were completed to create the base model of Svit:

- Generating the terrain using the game's inbuilt option for importing heightmaps in the PNG format (figure 9, box B).
- Calling GeoSkylines' method ImportRoads() to generate the road network in the game (figure 9, box C).
- Calling GeoSkylines' method ImportWaterWays() to generate water basins for waterways in the game (figure 9, box D).
- Calling GeoSkylines' method ImportWaterReservoirs() to generate water basins for resources of standing water in the game (figure 9, box D).
- Calling GeoSkylines' method ImportTreesRaster() to generate tree coverage in the game (figure 9, box D). Forested areas in the prepared PNG file covered a large part of the overall modelled area, resulting in breaching the limit of trees created (250,000). Therefore, the variable ImportTreesRasterMultiply was set to −2, meaning that every second creation of a tree will be skipped (i.e., dividing the total number of trees by 2).

Figure 18 displays the creation of Svit's base model in the game's map editor by calling the GeoSkylines import methods.

Figure 18 Creation of the base model of Svit from geographical data using the GeoSkylines methods. A: an empty map after opening the map editor, B: the map after uploading the terrain, C: the map after generating the road network, D: the map after generating basins with water sources and tree coverage.

7.2 Creation of the Olomouc base model

The city of Olomouc (Czech Republic) is the 6th biggest city in the country, with a population of 100,514 inhabitants (Havel, 2021). This city is very old, especially the centre, which contains many churches and other historic buildings. This city was selected for this research for its history and size. The mid-point of the modelled area was located to:

- CenterLatitude: 49.588705
- CenterLongitude: 17.247812

The selected mid-point was then used to calculate a geographical bounding box of 17.28 km x 17.28 km, representing the size of the Cities: Skylines game area. Next, the following geographical datasets were obtained for the Olomouc area:

- PNG heightmap generated from a DEM DMR5G tile using QGIS and the gdal_translate command:
  - gdal_translate -scale 136 1024 0 65536 -projwin 653819.734498533 5503970.495422958 671095.4346983728 5486693.562522869 -of PNG "C:/data/DMR/DMR 5G_1.tif" C:/data/DMR/OlHeightMap.png

- Step-by-step documentation on generating a PNG heightmap from a DEM tile is available at GeoSkylines's GitHub page (Pinos, 2020a) and in appendix 1.

- Road vector layer from OSM (tag *highway*). This layer was converted to the file roads_rwo.csv.
- Waterway layer from OSM (tag *waterway*). This layer was converted to the file waterway_rwo.csv.
- Water body layer from OSM (tag *natural=water*). This layer was converted to the file water_rwo.csv.
- PNG image of a tree coverage from the Urban Atlas Street Tree layer. This layer was clipped according to the defined area.
- Service vector layer from OSM (tag *amenity*). This layer was converted to a file amenity_rwo.csv.
- Dataset Funckni_plochy_zastavba_upraveno (derived from the dataset Functional Zones Olomouc) which combines the information about the function of a specific area with information about the type of housing in that area (Pavlis, 2019).

Next, matching files were prepared, where geographical object types were matched to appropriate game object types. Table 5 displays the matching used in the file rwo_cs_road_match.csv.

Table 5 Matching of OSM road (highway) types to Cities: Skylines road types.

OSM road type	Cities: Skylines road type
motorway	Highway2L2W
motorway_oneway	Rural Highway
trunk	Highway2L2W
trunk_oneway	Rural Highway
primary	Small Avenue
primary_oneway	Oneway Road
secondary	Small Avenue
secondary_oneway	One-Lane Oneway
tertiary	Basic Road
tertiary_oneway	One-Lane Oneway
unclassified	Basic Road
unclassified_oneway	One-Lane Oneway
residential	Basic Road
residential_oneway	One-Lane Oneway

motorway_link	HighwayRamp
trunk_link	HighwayRamp
primary_link	Oneway Road
secondary_link	One-Lane Oneway
tertiary_link	One-Lane Oneway
living_street	Basic Road
road	Basic Road
road_oneway	One-Lane Oneway

Other OSM road types were not used for generating the base model of Olomouc. Unwanted road types can be simply filtered out by not providing a match in the matching file (i.e. import method will skip these records). In the Table 5, note the derived types <road_type>_oneway. These were added to distinguish between one-way and two-way roads of the same type.

Table 6 displays the matching used in the file rwo_cs_service_match.csv.

Table 6 Matching of OSM service (amenity) types to Cities: Skylines service building types.

OSM service type	**Cities: Skylines service building type**
school_elem	Elementary School
school_high	High School
university	University
library	Library 01
hospital	Hospital
clinic	Medical Clinic
doctors	Medical Clinic
grave_yard	Cemetery
crematorium	Crematory
fire_station	Fire Station
police	Police Station

The OSM tag *amenity=school* marks both elementary and middle schools. Because of that the school tag in the service_rwo.csv dataset was manually modified to school_elem and school_high.

As for zoning, the file zones_rwo.csv was derived from the dataset Funckni_plochy_zastavba_upraveno. During the conversion, a new combined attribute zone_type was created. This attribute combines the values of attributes CS_class and density from the original dataset. Figure 19 shows the zoning in QGIS (the colouring of the zoning was set to match the colouring of the zoning in the game).

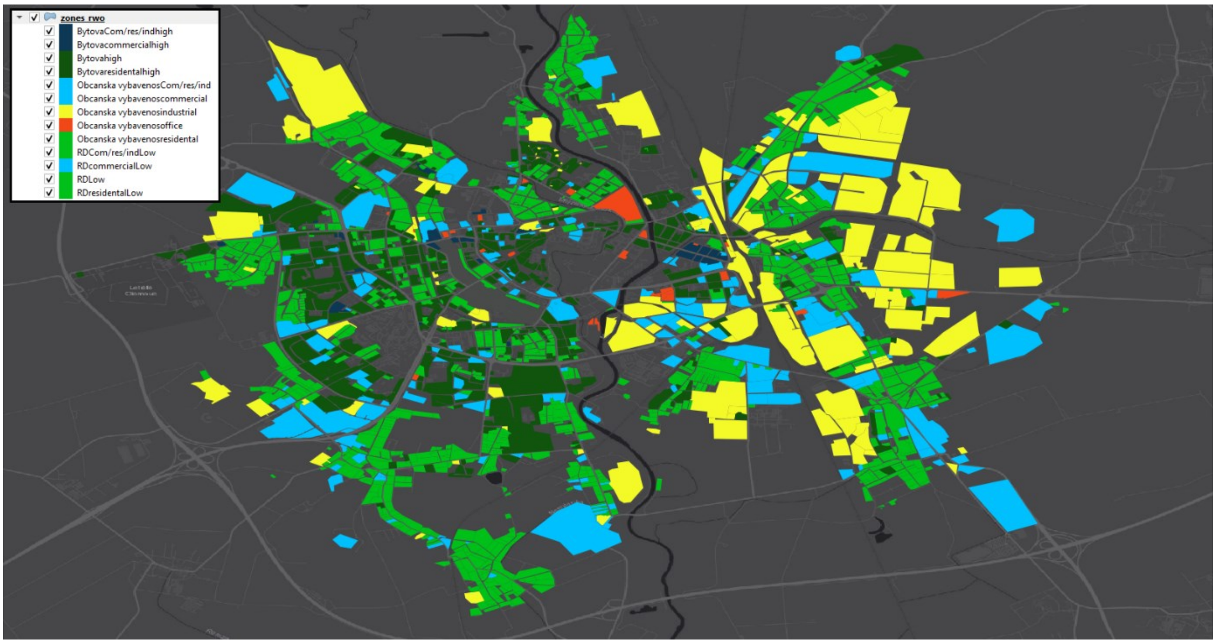

Figure 19 Zoning from the prepared file zones_rwo.csv. Colours adjusted to the matched game zone types (green represents residential areas, blue represents commercial areas, yellow represents industrial areas and red represents office areas).

Table 7 displays the matching used in the file rwo_cs_zone_match.csv.

Table 7 Matching of zone types used in the zones_rwo.csv file to Cities: Skylines zoning types.

Zone type in zones_rwo.csv	Cities: Skylines zoning type
BytovaCom/res/indhigh	ResidentialHigh
Bytovacommercialhigh	CommercialHigh
Bytovahigh	ResidentialHigh
Bytovaresidentalhigh	ResidentialHigh
Obcanska vybavenosCom/res/ind	CommercialLow
Obcanska vybavenoscommercial	CommercialLow
Obcanska vybavenosindustrial	Industrial
Obcanska vybavenosoffice	Office
Obcanska vybavenosresidental	ResidentialLow
RDCom/res/indLow	ResidentialLow
RDcommercialLow	CommercialLow
RDLow	ResidentialLow
RDresidentalLow	ResidentialLow

After preparing all datasets and matching files, the base model of Olomouc in Cities: Skylines was completed following the steps below:

- Generating the terrain in the game's map editor, using the inbuilt option for importing heightmaps in the PNG format.
- Manually adding at least 2 outside connections (highways) and a water source in the starting tile (required by the map editor to save the map as playable). This allows the rest of the model to be generated in the actual game rather than the map editor, where the generated results behave differently (e.g. roads are elevated by 1 meter). The added items are temporary and can be modified or deleted later.
- Calling GeoSkylines' method ImportRoads() to generate the road network in the game.
- Calling GeoSkylines' method ImportWaterWays() to generate water basins for waterways in the game.
- Calling GeoSkylines' method ImportWaterReservoirs() to generate water basins for resources of standing water in the game.
- Calling GeoSkylines' method ImportTreesRaster() to generate tree coverage in the game.
- Calling GeoSkylines' method ImportServices() to generate service buildings in the game.

Figure 20 displays the base model of Olomouc generated in the game by calling the import GeoSkylines methods.

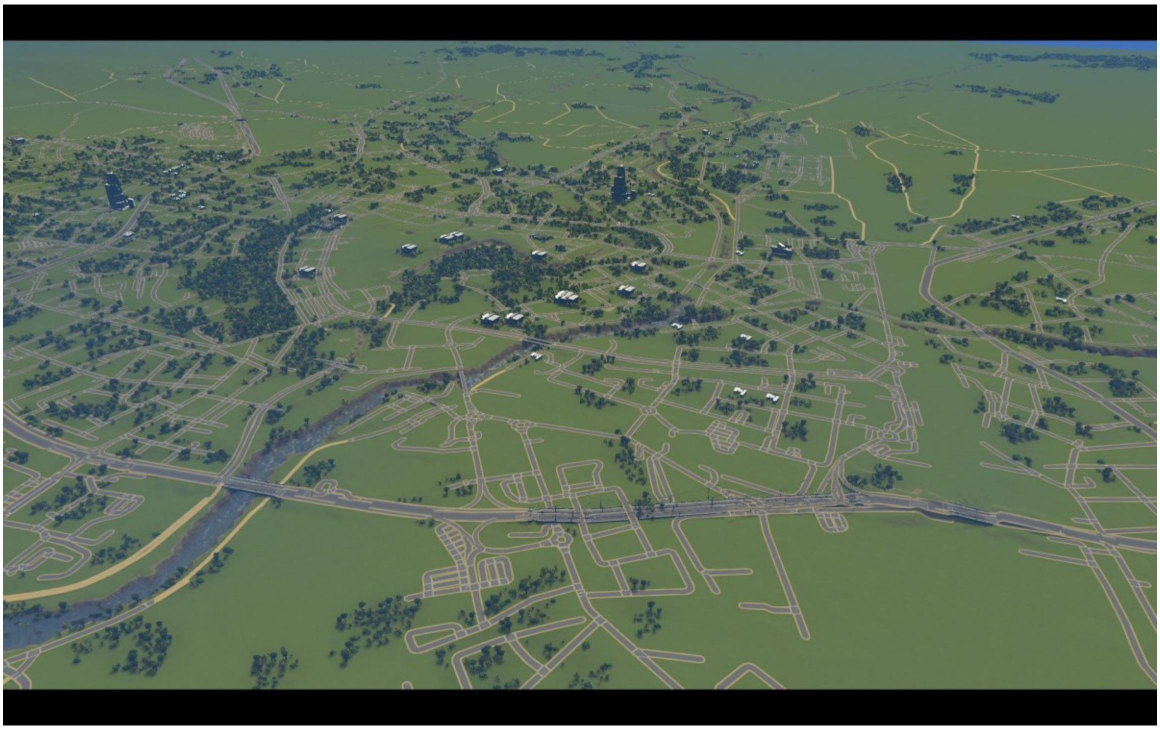

Figure 20 A base model of Olomouc in Cities: Skylines generated by calling GeoSkylines' methods.

7.3 Creation of a playable model of Olomouc

Using GeoSkylines' import methods for generating game objects from geographical data reduces the work necessary to create a model of a selected city. Nevertheless, manual post-processing is still required to turn the generated base model into a playable model that can be used for visualisation or simulation purposes. The manual post-processing of the Olomouc model consisted of the following stages:

- Adding water resources
- Fixing the road network
- Creating zoning (using the ImportZonesArea() method)
- Mitigating unrealistic simulation behaviour of the game
- Creating a public transport system
- Adding playgrounds, sport grounds, parks, and unique buildings such as churches and skyscrapers

7.3.1 Adding water resources

Water basins were generated by the GeoSkylines import methods. But adding the water must be done manually by placing one or more water sources. Due to the game's minimum width of 8 metres, it is difficult to model small streams such as the streams Bystřička or

Mlýnský potok. The narrow parts often prevent the water from flowing, resulting in many parts of the basin being empty. This issue was resolved by adding multiple water resources of the smallest size in different parts of the basin.

7.3.2 Fixing the road network

Though the generated road network is topologically connected, there are issues that require modifying. As discussed in objective 2, the GeoSkylines mod does not add elevation to the created roads. Therefore, all overpass roads and elevated bridges lay flat on the terrain. This issue can be fixed by elevating the roads with the Move It mod (*Move It*, 2019) or by recreating them using the game's Road tools.

Tram tracks are, in Cities: Skylines, often part of a road (e.g. Two-lane road with tram tracks). Generating roads with tram tracks from combined roads and railway geodata presented an obstacle. Therefore, in the Olomouc model the tram network was manually built using the game's transportation tool (the DLC Snowfall must be installed to construct a tram network). A tram depot was built in the place where the real Olomouc tram depot is located.

The geographical representation of junctions might include separate line geometries for turning lanes. The GeoSkylines mod successfully imports this type of representation, but the resulting junction slows down the vehicular agents in the game as they respond to the connected turning lanes as another junction. These junctions were simplified by removing the turning lanes and adding asymmetric roads as is shown in Figure 21.

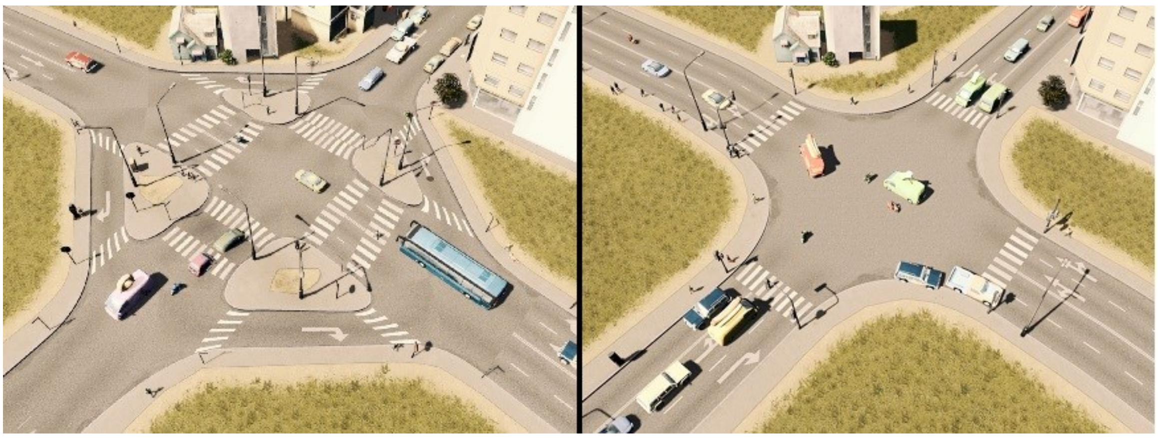

Figure 21 Simplifying junctions in Cities: Skylines to prevent slow traffic

As a last step, the road network must be connected to the outside world from which the citizens as well as the delivery trucks will arrive to the city. Outside connections were built for all arterial roads in the Olomouc area: D46, I46 and D35 (both ways).

7.3.3 Create zoning

After the road network is completed, the method ImportZonesArea() can be called. Alongside all roads (except highways), the game Cities: Skylines automatically generates a grid of zone blocks. The method ImportZonesArea() loops over all zone blocks and, based on a location match with the records from the file zones_rwo.csv, assigns a type of zone to it. Figure 22 shows the zoning imported to the model of Olomouc.

Figure 22 Zoning imported into the model of Olomouc.

The method ImportZonesArea() assigns the type of zone to all the available zone blocks, not leaving any gaps in between. This might cause a very high density of generated buildings. To lower the density, the zoning can be modified by adding gaps. Additionally, the size of the zone grid affects the size of the generated building. The largest grid (4 x 4 blocks) generates the largest buildings that are available in the game. These types of buildings were not appropriate for the Olomouc model, therefore the width of the majority of the zone grids was reduced to 3. Figure 23 shows a comparison of a zoned road before and after manual modification.

Figure 23 The imported zoning (left) was modified by adding gaps and limiting the width of the zone grids (right).

7.3.4 Mitigating unrealistic simulations of the game

Cities: Skylines is a game that aims to entertain, and thus some of the game's simulations are simplified whereas others present an unexpected challenge to the player. For example, the need for fire services is exaggerated in order to create a challenge for the player even at the early stages of the game. However, for larger cities the amount of fire services required is unrealistically high. In reality, there is only one major fire station in Olomouc, but adding only one fire station to the game model would result in constant fires. This and other unrealistic or unwanted behaviour of the game was mitigated or completely suppressed by installing selected mods that are described below. All mods are freely available on the platform Steam.

81 tiles

The game area is divided in 81 tiles (one tile is 1.92 km x 1.92 km). The player begins in the first starting tile and gradually, as the city grows, buys the remaining tiles. However, for creating a model of an existing city, unlocking the whole game area is required. The mod *81 tiles* does exactly that (*81 Tiles*, 2020).

Lifecycle Rebalance

When residential houses are built in Cities: Skylines, new citizens from outside the map will arrive to the city and start living there. The new citizens are a mix of young couples, families with children and seniors. The aging of the people in the game – when they grow up, when they start a family and when they die – is constant. This behaviour might result in sudden changes in population. E.g. a bigger number of seniors dying at once is known in the Cities: Skylines community as a "death wave". The sudden changes, especially the death waves, might become unmanageable when large areas are assigned a residential zone at once (this is the case when creating a model of a real-world city). To mitigate the death waves and other sudden changes in the population, the mod *Lifecycle Rebalance* was installed. This mod adds randomness to the aging of the citizens. Additionally, it modifies the transport preferences of the citizens based on their age group (*Lifecycle Rebalance Revisited 1.5.3*, 2020).

Realistic Population

Each type of building in the game is defined with a capacity – how many people can live or work there. In the original version, the capacity of some buildings is too low (tall residential buildings with only a few households) while for other buildings the capacity is too high. The mod *Realistic Population Revisited 1.4.3* modifies the numbers of households and jobs in buildings to reflect real-world values more accurately (*Realistic Population Revisited 1.4.3*, 2020). This mod helps to manage the population of the modelled city. Alternatively, the mod *Ploppable RICO Revisited 2.4.4* can be used (*Ploppable RICO Revisited 2.4.4*, 2020). Using this mod, the capacity of each building type can be modified.

Utility mods

A set of utility mods was used when creating a model of Olomouc. These mods do not change the simulation behaviour of the game in any way and are not required to run the model, yet they are highly recommended for creating a model of a real-world city. The mod *Find It* (*Find It!*, 2020) adds an advanced search bar for looking up any asset loaded in the game. The mod *Move It* (*Move It*, 2019) allows the player to move - horizontally as well as vertically - any game object such as a building, a road segment or a road nodes to any location. While moving the object, the mod recalculates the position and the relation of adjacent objects as well (e.g. moving a road node will change the shape and location of connected roads). The mod *Fine Road Anarchy* (*Fine Road Anarchy 2.0.2*, 2020) allows the breaching of most of the limitations for building roads (e.g. placing parallel roads next to each other).

Using the mod *Image Overlay* (*Image Overlay*, 2018), an overlay image can be uploaded to the game. This simple feature is very useful when creating or adjusting the game objects according to the geographical data. Additionally, this mod can be used to display any kind of geographical data in the form of a transparent image file. Figure 24 shows an example of an overlay of an aerial image which can be used to manually create a highway junction.

Figure 24 Aerial images loaded into Cities: Skylines can be used for recreating real-world places.

Suppressing unwanted behaviour

Some of the game behaviour that is not required for the goal of this research and only adds unnecessary complexity was completely suppressed in the game. The mods *Remove Need For Power Lines* and *Remove Need For Pipes* remove, as the names suggest, the requirement of building electricity and water infrastructure connecting to every house (*Remove Need For Pipes*, 2018; *Remove Need For Power Lines*, 2018). Mod *No Fires* simply turns off the chance of a fire in the city (*No Fires*, 2015). A building reporting a problem (crime, pollution, lack of jobs, etc.) which is not being addressed can eventually become abandoned. This behaviour is very sensitive and, in the case of creating a model of a real-world city, can produce large blocks of abandoned buildings. Therefore, the mod *No Abandonment*, which prevents abandoning buildings, was installed (*No Abandonment*, 2019). Last, the mod *Pollution, Death, Garbage and Crime Remover* (*Pollution, Death, Garbage and Crime Remover Mod*, 2016) was installed to minimize the number of garbage trucks, police cars and hearses in the streets.

The game's high demand for some services such as fire, health, death care or garbage collection services, can be addressed by building additional service buildings (these can be visually hidden); however, this can produce a hugely unrealistic number of service vehicles in the streets which then cause traffic jams. Ideally, the game should offer an option to set the sensitivity of the services. But at the time of this research, this option was not available in the game nor in any of the mods. Hence some of the behaviour, as described above, was suppressed.

7.3.5 Public transport system

After completing the road, tram and railway network, the public transport system – consisting of tram, bus, and train lines – was established. Required depots for buses and trams were placed in the game where the real depots are located (Sokolská Street). Applicable geographical data for lines of public transport were not found, therefore the most frequent transport lines and their stops were recreated in the game manually, according to the information from Dopravní podnik města Olomouce (*Zastávkové Jízdní Řády Olomouc*, 2021). Figure 25 shows the public transport system of the model of Olomouc, with the tram lines coloured in black, bus lines coloured in purple and train lines coloured in orange.

Figure 25 Transport system of the model of Olomouc. Tram lines are represented in black, bus lines are represented in purple and train lines are represented in orange.

Table 8 below lists all transport lines created in the model of Olomouc.

Table 8 Transport lines in the model of Olomouc.

Number/name	**Type**	**Route**	**Number of stops**
1	Tram	Main station – Nová Ulice	20
2	Tram	Main station – historic centre - Neředín	26
3	Tram	Main station – historic centre - Povel	22
4	Tram	Pavlovičky – historic centre – Nová Ulice	32
5	Tram	Main station - Povel	12
7	Tram	Main station – Neředín	26
11	Bus	Main station – Sv. Kopeček	20
16	Bus	Nová Ulice – city centre – Nové Sady	29
17	Bus	Černovír – city center - Slavonín	27
20	Bus	Černovír – city centre - Horka	30
22	Bus	Černovír – city center – Nový Svět	19
29	Bus	Globus (Neředín) – city centre - Povel	20
NedveziBystrocice	Bus	City centre – Nedvězí - Bystročice	3
TynecGrygov	Bus	City centre – Týnec - Grygov	5
KozusanyBlatec	Bus	City centre – Kožušany - Blatec	4
Dolany	Bus	City centre - Dolany	10
VHorka	Train	Main station – Olomouc město - Horka	12
VBlatec	Train	Bystrovany - main station - Blatec	6
VGrygov	Train	Hlušovice – main station - Grygov	4

Though several transport lines were not recreated, the resulting public transport system provided the citizens an overall good connection in the Olomouc model.

7.3.6 Leisure and unique buildings

Adding leisure and unique buildings to the model was not critical for the goal of this research; however, it increases the simulated happiness of the citizens as well as the visual attractivity of the whole model. Playgrounds and some sports grounds were placed where real playgrounds exist. Custom assets downloaded from Steam workshop were used for creating churches, fountains, and a few high-rise buildings. Figure 26 shows two examples of unique buildings added to the model of Olomouc.

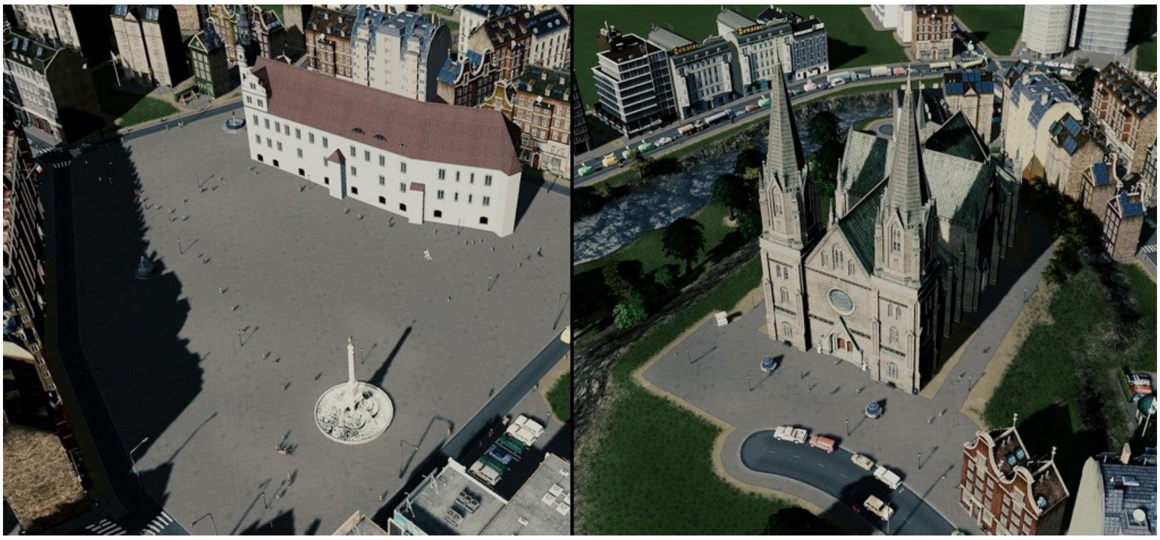

Figure 26 Unique buildings in the model of Olomouc. On the left, the custom assets Hartenfels Castle and FontaineDuPalmier were added to model the square Horní Náměstí. On the right, the in-game asset Cathedral of Plentitude was used to model the Saint Wenceslas Cathedral.

7.4 Model of Olomouc

The final model of Olomouc was created with the help of the import methods of the GeoSkylines mod as well as manual modifications. The majority of the buildings in the model were generated by the game engine (rather than individual placement of each building), hence the more generic look of the model. The aim was to create a model that is easy to use and share. In this regard, the model runs without any issues. The model, the list of required mods and the list of used custom assets were published on the platform Steam (Pinos, 2020c, 2020e, 2020d). The model is included as appendix 2.

The model consists of the city of Olomouc and its neighbourhoods (defined as districts in the game) – Olomouc Město, Hejčín, Řepčín, Tabulový Vrch, Neředín, Černovír, Lazce, Nová Ulice, Nové Sady, Povel, Nový Svět, Hodolany, Pavlovičky, Holice, Bělidla, Chválkovice and Týneček – and surrounding villages and small towns – Slavonín, Nemilany, Kožušany, Blatec, Nedvězí, Bystročice, Hněvotín, Ústín, Příkazy, Skrbeň, Břuchotín, Horka nad Moravou, Křelov, Chomutov, Hlušovice, Dolany, Tovéř, Samotišky, Svatý Kopeček, Droždín, Velká Bystřice, Bystrovany, Velký Týnec, Vsisko and Grygov. The modelled area covers the majority of the boundary of the Olomouc municipality (a small part near the town of Hlubočky is not included). The population of the whole model is around 110 thousand people. Figure 27 shows the overall population statistics from the model of Olomouc.

Figure 27 Population statistics of the model of Olomouc.

The mod *CSL Show More Limits* provides the information about the number of objects created in the game (*CSL Show More Limits*, 2017). Figure 28 shows the number of created game objects and the maximum limits. The number of created segments (includes roads, pedestrian paths, and railways) is 29,841 out of a maximum of 36,352. The number of created road nodes is 28,948 out of a maximum of 32,256. The number of active vehicles is 7,836 out of a maximum of 16,384. This means that the traffic simulations are not limited by the maximum number of active vehicles.

Figure 28 The numbers of created game objects.

Figure 29 shows the city centre of the final model of Olomouc. For comparison, Figure 30 shows the aerial image of the historic centre of the city of Olomouc.

Figure 29 A playable model of Olomouc in Cities: Skylines (historic centre).

Figure 30 Aerial image of Olomouc (historic centre), data source: http://maps.google.com.

Figure 31, Figure 32 and Figure 33 show other examples of the final model of Olomouc.

Figure 31 A playable model of Olomouc in Cities: Skylines (river view).

Figure 32 A playable model of Olomouc in Cities: Skylines (in front of the train station).

Figure 33 A playable model of Olomouc in Cities: Skylines (crossing of the roads Velkomoravská and Brněnská)

7.5 Model of Olomouc by Silvaret

Silvain Hamar de la Brethonière, in the gaming community best known as ‚Silvaret', is an experienced Cities: Skylines player who specializes in real-world city recreations in Cities: Skylines. Silvaret created the model of Oslo for the project at NMBU (Grande, 2019). He also created a model of Brussels as part of his master's thesis *The digital urban model: Cities: Skylines* *as a gamified tool for public engagement in urban planning*(Brethonière, 2020). Due to our mutual interest in researching the application of Cities: Skylines in urban planning, Silvaret offered to create a model of Olomouc as well. The starting point for Silvaret's model was also the base model of Olomouc that was generated using the GeoSkylines import methods. However, rather than letting the game generate buildings at random according to the assigned zone, Silvaret used the technique of individual placement for most of the buildings in the model. This technique greatly increases the visual attractivity of the model as well as the resemblance to the real-world city. This technique was done using the mod *Ploppable RICO Revisited 2.4.4* (*Ploppable RICO Revisited 2.4.4*, 2020). Figure 34, Figure 35, Figure 36 and Figure 37 show Silvaret's model of Olomouc.

Figure 34 Model of Olomouc by Silvaret (view of the historic centre).

Figure 35 Model of Olomouc by Silvaret (residential area Tabulový vrch).

Figure 36 Model of Olomouc by Silvaret (detail of prefabricated block houses on Foerstrova street).

Figure 37 Model of Olomouc by Silvaret (view of the whole model).

8. UTILISATION OF PLAYABLE MODELS FOR SPATIAL PLANNING

As part of this objective, the created model of Olomouc in Objective 3 was tested in two case studies in spatial planning. The first case study was a geo-participation project in which players were asked to design a new part of a city in the game. The game provides an environment enabling the users to cross the technology gap and design a model without the need for knowledge of GIS or CAD systems. Geo-participation represents the latest trend in Public Participation GIS (Pánek, 2016).

For this case study a suitable area intended for development had to be selected. The following development activities of the city of Olomouc were considered:

- New neighbourhood VOP Velkomoravská
- Highway bypass connecting arterial roads D/35, I/55 and I/46
- Extending the tram line from Povel to Nové Sady

From the options above, designing a whole neighbourhood with all its elements and connections to other parts of the city gives the players the most space for creativity and imagination. From this point of view, designing a new neighbourhood is the most preferred option for a contest. Furthermore, the above options were consulted with city representatives who confirmed that the option of designing a new neighbourhood VOP Velkomoravská is most suitable. The design project happened in five stages:

1. Preparing the design rules
2. Starting the design contest
3. Creating designs, collecting designs & creating presentation material
4. Assessing the designs
5. Gathering feedback from the players and the jury

The game Cities: Skylines offers numerous simulations such as noise pollution, land price, crime, etc. In the second case study the focus was given to selected traffic simulations in the created model of Olomouc. The traffic density in the model of Olomouc was monitored for the whole road network as well as for particular scenarios that involve modifying the infrastructure.

8.1 Olomouc VOP Velkomoravská – designing a new neighbourhood in Cities: Skylines

The city of Olomouc is planning to redevelop a former military compound and the surrounding localities into a mixed residential area. The area in question is referred to in the city's masterplan as VOP Velkomoravská (*Územní Plán Olomouc*, 2020). After consultation with the city representatives, this area was selected for a design project in the game Cities: Skylines, where players from the gaming community were asked to create their own design for the area. The aim of this case study was to test the ability of Cities: Skylines to create designs that are attractive, comprehensible, and effective for both the public and the experts, and whether this game could be used as tool for geo-participation.

VOP Velkomoravská is roughly bounded by the streets Velkomoravská, U rybářských stavů, Přichystalova and Holická. The boundary of this area is shown in Figure 38.

Figure 38 Boundary of the VOP Velkomoravská.

The area consists of the following localities defined by the city's masterplan:

- 12/056P – former military compound
- 12/054Z and 12/051N – mostly fields
- 12/055S, 12/053S and 12/117S – existing housing (which was ignored for the design purposes)

The largest part of VOP Velkomoravská is a former military compound that has been closed to the public for many years. The compound is now abandoned with most of its buildings left in ruins, making the area unattractive. Furthermore, the area's inaccessibility has created a division between the surrounding city parts Nový Svět and Povel, and Nový Svět and the city centre.

The goal of the design was to create a modern and attractive neighbourhood in the VOP Velkomoravská area, which will consist of residential and commercial housing as well as public spaces and local services such as doctors. The new neighbourhood should also remedy the current division by sufficiently connecting it with the surrounding city areas: Nový Svět, Nové Sady, Povel and the city centre.

8.1.1 Design criteria

All designs were required to follow the criteria which are stated below. These criteria are based on the regulatory plan defined for the VOP Velkomoravská area in the city's masterplan. However, only the most important rules were selected, and the wording was simplified in order to communicate it better to the interested players. The file Olomouc_VOP.pdf stating the design criteria are included in appendix 3.

Area

The design must be located within the specified boundaries. An image file was prepared to easily display the boundary of VOP Velkomoravská. This image can be loaded into the game using the Image Overlay mod. Figure 39 shows the prepared overlay image of VOP Velkomoravská in the game.

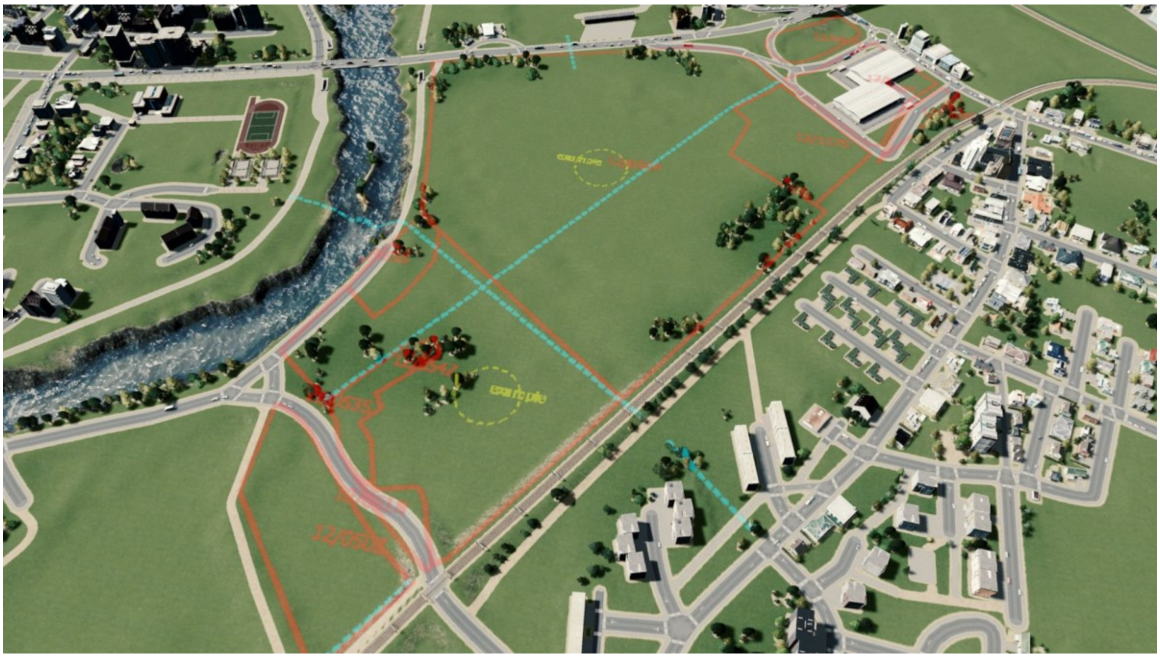

Figure 39 Overlay image of the boundary of VOP Velkomoravská loaded in Cities: Skylies.

Residential housing

Most of the housing used in the design should be residential. According to the city's masterplan, around 40% of the VOP Velkomoravská area should be dedicated to residential housing.

Public spaces and greenery

The design should include enough public spaces (parks, squares, or other meeting places) and greenery. According to the city's masterplan, in the area, there must be one public space at 12/056P as well as one public space at 12/054Z. In both cases the area of the public spaces must be at least 0.3 ha, the side ratio must range from 1:1 to 1:3 (i.e. noodle shaped spaces are not allowed). Aside from the public spaces, around 30% of the VOP Velkomoravská area should be dedicated to greenery.

Infrastructure & connectivity

The design should connect VOP Velkomoravská with neighbouring areas. Additionally, the area should be connected to a public transport system. The city's masterplan defines pedestrian paths connecting to neighbouring areas. An image file was prepared to display the planned pedestrian paths in the VOP Velkomoravská area. The pedestrian paths are represented by blue dotted lines (as seen in Figure 39). The path from Přichystalova street to Jeronýmova includes a pedestrian bridge over the Morava river. The city's masterplan requires a connection to the public transport system as well; a bus connection is considered the most appropriate. Furthermore, the city's masterplan also requires adequate flood protecting measures to be installed between the Morava river and VOP Velkomoravská.

Building height limitation

The design should not include buildings higher than 6 floors. According to the city's masterplan, the maximum height of buildings in this area should be 17/21 meters (edge of the building / top of the roof). However, this criterion was considered with a tolerance (especially for unique buildings).

Services

The design must include a kindergarten within VOP Velkomoravská. Placing other local services was optional.

8.1.2 Starting the VOP Velkomoravská design contest

The starting model, the list of required mods and the list of custom assets were published on the platform Steam (Pinos, 2020c, 2020e, 2020d). Information about the design rules, the starting model, the supporting materials as well as the instructions for submitting a design were summarized in the document Olomouc_VOP.pdf (included in appendix 3). The design contest was announced on the platform Reddit, specifically in the subreddit dedicated to Cities: Skylines (Pinos, 2021l). To increase the awareness of the contest, the link to the Reddit page was shared on social networks, especially on channels or groups dedicated to Cities: Skylines. The time for submitting a design was set to 2 and half weeks, from the announcement on the 6th of January 2021 to the 24th of January 2021.

8.1.3 Creating designs, collecting designs & creating presentation material

The design contest was open for two and half weeks. In the meantime, I tested the aspects of geo-participation myself by recreating the architectural design of VOP Velkomoravská by Roman Hrabánek. Additionally, the submitted designs were tested and the presentation material was prepared.

Recreating Hrabánek's design of VOP Velkomoravská in Cities: Skylines

In the contest URBAN DESIGN AWARD 2018/2019, Roman Hrabánek presented a design of a new neighbourhood in the VOP Velkomoravská area (Hrabánek, 2019). This design was awarded with second place. In order to experience the participation in the design project myself, I decided to recreate Hrabánek's design in Cities: Skylines. First, based on the available design documents, I prepared an overlay image that aided me in the construction of roads. Next, using the mod *Plop the Growables* (*Plop the Growables*, 2019), each building was individually placed. Using the mods *Find It* and *Move It*, various decorations such as trees or leisure items were placed in the public spaces. Additionally, a few unique buildings were created using the mod *Procedural Objects* (*Procedural Objects*, 2017). This mod allows a game user to modify the shape of any game object by changing its size, elevation and rotation. Figures 39-42 show examples of Hrabánek's design recreated in Cities: Skylines.

Figure 40 VOP Velkomoravská according to the design by Roman Hrabánek (aerial view).

Figure 41 VOP Velkomoravská according to the design by Roman Hrabánek (high residential housing blocks with recreational elements).

Figure 42 VOP Velkomoravská according to the design by Roman Hrabánek (low residential housing blocks with a park).

Figure 43 VOP Velkomoravská according to the design by Roman Hrabánek (open entrance to the neighborhood from Velkomoravská road).

Collecting the designs & preparing presentation materials

Ten designs were submitted in total. Eight of the designs included a model (either published on Steam or shared using an alternative way); one design was presented as a PDF report and one was accompanied only with screenshots and a short description. All provided models were tested in Cities: Skylines. Testing the models highlighted two problems: long loading times and the chance of technical difficulties when opening a model. To prevent these problems from happening during the assessment, I decided to prepare a video presentation of each design. All videos were similarly structured, ranging from 3 to 5 minutes long, depending on the amount of information provided. Presenting designs with videos with similar structure also made them more comparable.

Design by Jan Piňos

This design is based on the architectural design of Roman Hrabánek. This design is described in detail above and in the published video presentation (Pinos, 2021d).

Design by Jessie G

VOP Velkomoravská in this design is connected to the street U rybářských stavů. There is no direct connection from Velkomoravská street. On the contrary, the designed neighbourhood is protected from this noisy street by a barrier of greenery. There is also a pedestrian overpass to safely cross Velkomoravská street. The housing in this design is mostly low residential, with one street dedicated to high residential housing. A uniform style of architecture was used for the housing. The design includes enough green and public spaces which are placed thorough the whole neighbourhood. The design included a shop area with a local supermarket (Pinos, 2021e). Figure 44 shows the aerial view of the design by Jessie G.

Figure 44 VOP Velkomoravská according to the design by Jessie G.

Design by Ian Witte

This design was presented in a PDF report with a detailed description. An informative map of the design was included as well. VOP Velkomoravská in this design is safely connected to the street Velkomoravská as well as to the streets U rybářských stavů and Holická. In the centre of the VOP Velkomoravská area is a square with shops and a few high residential buildings. The rest of the housing in this design is low residential. The road from the centre of the VOP Velkomoravská to Holická is designated for buses only to prevent throughgoing traffic. The riverbank was modified to include sufficient flood protecting measures in the form of a dike and flooding fields. The flooding fields also serve as a relaxation area (Pinos, 2021c). Figure 45 shows the aerial view of the design by Ian Witte.

Figure 45 VOP Velkomoravská according to the design by Ian Witte.

Design by Andrew C Webb

VOP Velkomoravská in this design is connected to the streets Velkomoravská and U rybářských stavů. The main idea of this design was the creation of a centralized main street with high-rise buildings with a mixed use: the ground floor dedicated to shops and restaurants and upper floors dedicated to residential living. Additionally, the wide sidewalks on the main street could be used for street markets and other local events. A low residential area is located between the main street and the river. Large parks are located on the opposite side, between the main street and the railway (Pinos, 2021a). Figure 46 shows the aerial view of the design by Andrew C Webb.

Figure 46 VOP Velkomoravská according to the design by Andrew C Webb.

Design by Niko Eriksson

VOP Velkomoravská in this design is connected to Holická street. The neighborhood is protected from the noisy street Velkomoravská by a large walkable park and a football field. The housing in this design is only high residential, mostly situated in blocks. The housing blocks – two have a completely enclosed interior courtyard – provide a local space for the inhabitants. A shopping street is located in between the two closed housing blocks. This design also includes a variety of sports grounds and more parks in the southern area (Pinos, 2021f). Figure 47 shows the aerial view of the design by Niko Eriksson.

Figure 47 VOP Velkomoravská according to the design by Niko Eriksson.

Design by Ross C

In this design, VOP Velkomoravská is safely connected to Velkomoravská street as well as to the streets U rybářských stavů and Holická. The neighbourhood is protected from the noise of Velkomoravská street by a barrier of greenery. The design includes two areas with high-rise prefabricated buildings (similar to buildings in other parts of Olomouc such as Nový Svět). The rest of the neighbourhood is dedicated to family houses. There are three shop areas in the design, so that the distance to shops is walkable for inhabitants of the neighbourhood. The centrepiece of the design is a large roundabout with a plaza (Pinos, 2021h). Figure 48 shows the aerial view of the design by Ross C.

Figure 48 VOP Velkomoravská according to the design by Ross C.

Design by Ossi Lämsä

In this design, VOP Velkomoravská is safely connected to the street Velkomoravská as well as to the streets U rybářských stavů and Holická. The neighbourhood is protected from the noise of Velkomoravská street by a barrier of greenery. The centrepiece of the road network is a roundabout dividing the traffic into four directions. Near the roundabout are shops, local services, and a playground. The design includes three blocks with high-rise prefabricated buildings (similar to buildings in other parts of Olomouc such as Nový Svět). These housing blocks are protected by hedges. The remaining housing consists of large suburban houses that are located on dead-end side streets (cul-de-sac style) (Pinos, 2021g). Figure 49 shows the aerial view of the design by Ossi Lämsä.

Figure 49 VOP Velkomoravská according to the design by Ossi Lämsä.

Design by siro300104

VOP Velkomoravská in this design is connected to the streets Holická and U Rybářských stavů. The neighbourhood is protected from the noisy street Velkomoravská by a barrier of greenery. The centrepiece of this design is a large plaza where inhabitants of the neighbourhood can meet, relax, or attend a local event. High-rise buildings with mixed use are located around the plaza. These buildings have ground floors dedicated to shops. More shops are located on the main street that connects the street U Rybářských stavů, the plaza and the street Holická. Apart from the high-rise buildings, the housing consists of low residential suburban houses (Pinos, 2021i). Figure 50 shows the aerial view of the design by siro300104.

Figure 50 VOP Velkomoravská according to the design by siro300104.

Design by Silvaret

VOP Velkomoravská in this design is connected to the street Velkomoravská, U rybářských stavů and Holická. This design works closely with the street Velkomoravská: adjacent to the street are residential and commercial buildings and a large sports hall. The housing is mostly situated in blocks of high-rise buildings. Each block offers the inhabitants a local space with greenery. The density of the housing lowers to the south. A commercial area is located around the sports hall where a large amount of pedestrian traffic is expected. The riverbank is reinforced with a retention wall protecting the neighbourhood against flooding. The retention wall also serves as a promenade (Brethonière, 2021). Figure 51 shows the aerial view of the design by Silvaret.

Figure 51 VOP Velkomoravská according to the design by Silvaret.

Design by Stephan K

In this design, VOP Velkomoravská is safely connected to Velkomoravská street as well as to the streets U rybářských stavů and Holická. The whole area in this design is dedicated to residential living with no high-rise buildings, creating a calm neighbourhood. Several small parks were placed thorough the neighbourhood. There are numerous park paths connecting parts of the neighbourhood., ensuring good walkability in the whole area (Pinos, 2021j). Figure 52 shows the aerial view of the design by Stephan K.

Figure 52 VOP Velkomoravská according to the design by Stephan K.

Design by Christopher A

The main idea of this design was the extension of an existing tram line from the street Švýcarské nábřeží over the river bridge to VOP Velkomoravská. The neighbourhood is also accessible for cars from the streets Velkomoravská, Holická and U rybářských stavů. A commercial area is placed near the river, creating a local centre of the neighbourhood. An area with high-rise prefabricated buildings (like buildings in other parts of Olomouc such as Nový Svět) is located next to the railway. The rest of the housing consists of small family houses (Pinos, 2021b). Figure 53 shows the aerial view of the design by Christopher A.

Figure 53 VOP Velkomoravská according to the design by Christopher A.

8.1.4 Design assessment

The overall assessment of designs was composed to include two parts: parametrical rating of the model and the rating of the jury. Most of the parameters in the parametrical rating were based on the design rules (i.e. according to the city's masterplan). The remaining added parameters represent meaningful objectives in spatial planning. Each parameter is described below:

- Within area: designs must be within the specified area
- 40% residential housing: rates the density of housing in the area
- 30% greenery: rates the density of greenery in the area
- Public space 12/056P: rates the quality of public space(s) in the locality 12/056P
- Public space 12/054Z: rates the quality of public space(s) in the locality 12/054Z
- Building height: points may be deducted if buildings higher than 6 levels are present in the design
- Connection to neighbourhoods: rates the overall connectivity to neighbouring city areas
- Connection to public transport: rates how effectively the area is connected to the public transport system

- Parking: rates how parking is accounted for in the design
- Shops: rates the quality of commercial areas in the design
- Local space: rates the quality of spaces where the area's inhabitants can have privacy or interaction with neighbours
- Pedestrian connection to Nový Svět: rates the connection
- Pedestrian connection to Povel (bridge): rates the connection
- Pedestrian cross Velkomoravská: rates the connection with areas beyond Velkomoravská
- Kindergarten: rates whether a kindergarten is present in the design
- Flood protecting measures: rates the quality of the flood protecting measures in the design
- Riverbank recreation: rates the use of the riverbank, especially for recreation
- Playgrounds and sports grounds: rates the use of playgrounds and sports grounds in the design
- Bike paths: rates the use of bike paths in the design

The parameters were split into three priority groups. In the highest priority group, the parameter could be rated in a range of 0-3. Accordingly, the second highest priority group had a range of 0-2 and the last priority group had the range of 0-1. In the below table, the priority groups are distinguished by shade. The criteria in italics were not specifically stated by the design rules. Table 9 shows the parametrical rating of the designs.

Table 9 Parametrical rating of the VOP Velkomoravská designs.

contestant	**Within area**	**40% residential housing**	**30% greenery**	**Public space 12/056P**	**Public space 12/054Z**	**Building height**	**Connection to neighbourhoods**	**Connection to public transport**	*Parking*	*Shops*	*Local space*	**Pedestrian conn. to Nový Svět**	**Pedestrian bridge to Povel**	**Pedestrian cross Velkomoravská**	**Kindergarten**	**Flood protecting measures**	*Riverbank recreation*	*Playgrounds and sports grounds*	*Bike paths*	**Total**
Piňos (Hrabánek)	2	3	2	2	1	2	2	2	0	2	1	1	1	0	1	0	1	1	0	24
Jessie G	3	3	3	2	2	2	1	1	2	2	2	1	1	1	1	1	0	0	0	28
Ian Witte	3	1	3	2	2	2	3	2	1	1	2	1	1	0	1	1	1	1	1	29
Andrew C Webb	3	2	3	2	2	2	2	1	2	2	1	1	1	0	1	1	0	1	1	28
Niko Eriksson	3	3	3	2	2	2	1	2	1	2	1	1	0	0	1	0	0	1	0	25

Ross C	3	1	2	2	2	2	2	1	1	2	1	1	1	0	1	0	0	1	0	23
Ossi Lämsä	3	1	3	2	2	2	2	2	2	1	2	1	1	1	1	0	0	1	0	27
siro300104	3	1	2	0	2	2	2	2	1	2	2	1	1	0	1	1	1	1	0	25
Silvaret	3	3	2	1	2	2	2	2	1	2	1	1	1	1	1	1	0	1	0	27
Stephan K	3	1	2	1	1	2	2	1	1	0	2	1	1	0	1	1	0	1	0	21
Christopher A	3	2	2	1	1	2	2	2	1	2	1	1	1	0	1	0	0	0	0	22

Next, the designs were assessed by a jury. The following experts accepted an invitation to the jury:

Doc. Jaroslav Burian, Ph.D.

Jaroslav Burian is an associate professor at the Department of Geoinformatics at Palacky University Olomouc. He specializes in geoinformatics in human geography, urban and spatial planning, and urban modelling.

Doc. Jiří Pánek, Ph.D.

Jiří Pánek is an associate professor at the Department of Development and Environmental Studies at Palacky University Olomouc. He specializes in participation in spatial planning and gamification.

Ing. arch. Petra Růžičková

Petra Růžičková is an architect working at the Department of Strategy and Management of the city of Olomouc and as such is overseeing planned developments in the city.

Mgr. Pavla Hluštíková

Pavla Hluštíková is a representative of the development company RedStone Real Estate. RedStone is the property owner of the locality VOP Velkomoravská.

On 17th February 2021, the designs were presented in an online video call to the jury and the designs were assessed (Pinos, 2021k). Table 10 shows the rating of the designs by the jury.

Table 10 Rating by the jury of the VOP Velkomoravská designs.

contestant	Jaroslav Burian	Jiří Pánek	Petra Růžičková	Pavla Hluštíková (RedStone)	Total – rating by the jury	Parametrical rating + rating by the jury
Piňos (Hrabánek)	4	3	4	4	15	39
Jessie G	3	2	2	3	10	38
Ian Witte	4	4	3	3	14	43
Andrew C Webb	3	2	3	2	10	38
Niko Eriksson	4	3	3	3	13	38
Ross C	2	3	1	1	7	30
Ossi Lämsä	3	3	1	1	8	35
siro300104	3	3	2	2	10	35
Silvaret	4	5	4	3	16	43
Stephan K	3	2	2	3	10	31
Christopher A	2	2	1	2	7	29

In the overall rating (combining the parametrical rating with the rating of the jury), the best rated designs were:

1. – 2. Silvaret and Ian Witte (with a total score 43)

3. – 5. Jessie G, Andrew C Webb, and Niko Eriksson (with a total score 38)

Due to a conflict of interest (i.e. designing the rating system), the recreation of Hrabánek's design was excluded from the awards. However, this design was presented to the jury as well.

Figure 54, Figure 55, Figure 56 and Figure 57 show more examples from the two winning designs.

Figure 54 VOP Velkomoravská according to the design by Silvaret (sports hall at the entrance from Velkomoravská road).

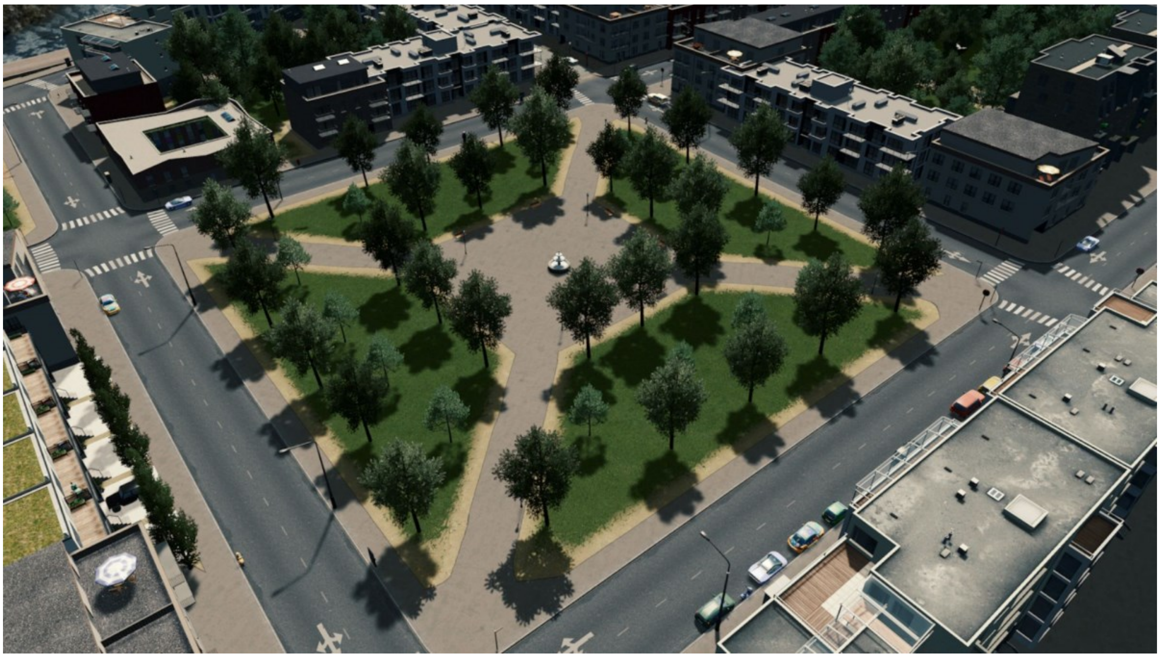

Figure 55 VOP Velkomoravská according to the design by Silvaret (park in between housing blocks).

Figure 56 VOP Velkomoravská according to the design by Ian Witte (central square with shops).

Figure 57 VOP Velkomoravská according to the design by Ian Witte (dike and flooding plains at the riverbank).

8.1.5 Feedback to VOP Velkomoravská design contest

This case study also included the gathering of feedback from both the players who participated in the design contest and the members of the expert jury who assessed the designs.

Players' feedback

The goal of gathering feedback from the players was to identify improvements to make for a future design contest or for the general use of Cities: Skylines for practical application. An anonymous questionnaire was sent to all participants (10) of the design contest to collect their feedback. Seven responses were submitted. The questionnaire consisted of 11 questions. Questions 1 to 5 collected feedback on the VOP Velkomoravská design contest. These questions were asked in the form of a statement which the respondents ranked on a scale from 1 (strongly disagree) to 5 (strongly agree). In question 1, "*The rules of the design contest were comprehensible*", three respondents agreed (4) and four responded strongly agreed (5) with the statement. In question 2, "*The rules of the design contest were strict*", one respondent strongly disagreed (1), whereas three respondents agreed (4) with the statement. Remaining three respondents found the rules moderately strict (3). In question 3, "*The provided materials - model, collection of mods and assets, overlay images - were sufficient for completing the design*", one respondent agreed (4) and six respondents strongly agreed (5) with the statement. In question 4, "*the provided starting model was easy to install and start*", three respondents agreed (4) and four respondents strongly agreed (5) with this statement. The same responses were registered for question 5, "*Submitting my design and the supporting materials was simple*".

The responses to questions 1, 3, 4 and 5 suggest that there were no major technical difficulties in starting the model, creating the design, or submitting it. However, the responses to question 2 suggest that the rules of the design contest could have been simpler. Excessively strict rules might discourage many players from participating in a design contest. On the other hand, the design rules must follow the regulations of the modelled area stated in the masterplan if the designs are to be assessed professionally. Finding the fine line between a professional and a playful approach could be the most important task for any future design contest in Cities: Skylines, or any game for that matter.

Question 6 asked about the contestant's interest in a future design contest. Two respondents agreed (4) and five respondents strongly agreed (5) with the statement "*I would be interested in future design contests in Cities: Skylines*".

In question 7, the contestants were asked to rank the motivation of several aspects to participate in a Cities: Skylines design contest. The respondents could rate the motivation level of the aspects as low, neutral, or high. Figure 58 shows the responses for question 7.

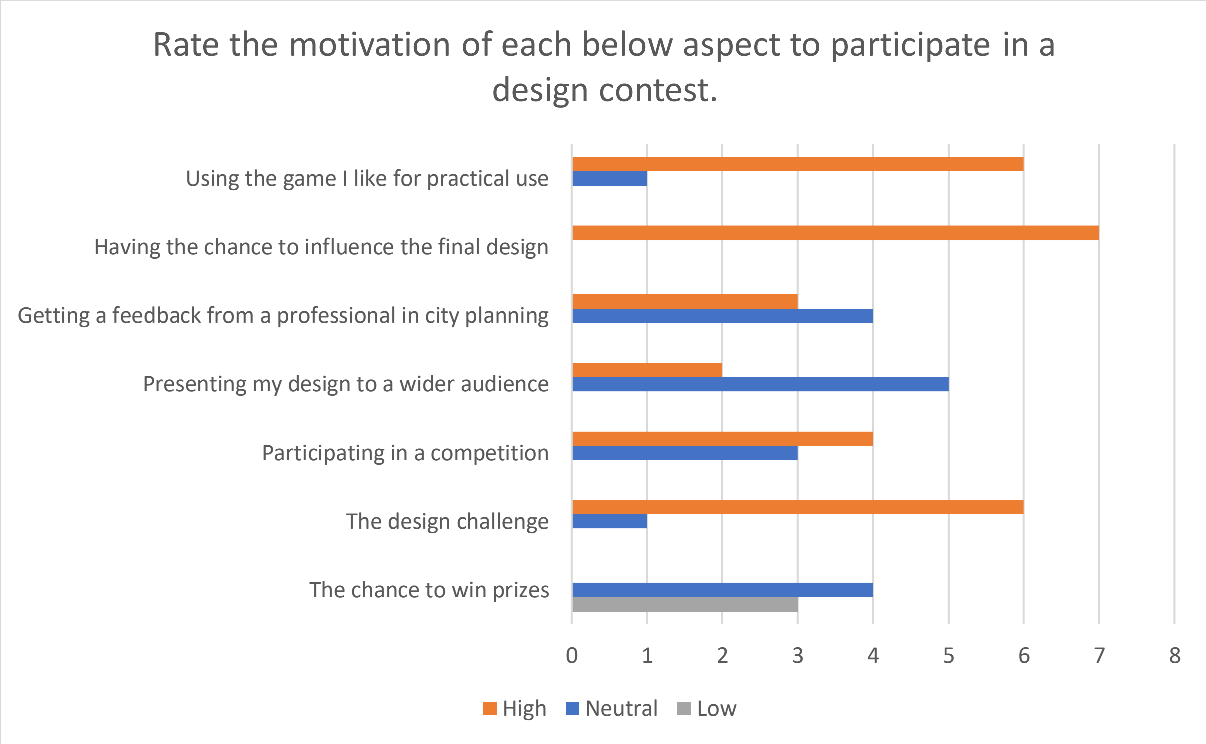

Figure 58 Respondents ranking the motivation levels of various aspects to participate in a Cities: Skylines design contest.

Surprisingly, the chance to win a prize was the least motivating aspect. Three responses rated the motivation level of this aspect as low and four responses as neutral. On the contrary, the most motivating aspect is the chance to influence the final design. All responses rated the motivation level of this aspect as high. Additional highly motivating aspects were the design challenge and the use of the game Cities: Skylines for practical purposes. In both cases one response rated the motivation level of these aspects as neutral and the remaining responses rated the motivation level as high.

In the 8th question, respondents were asked to select their level of experience with the game Cities: Skylines on a range from 1 (new beginner) to 5 (an expert with 1000+ hours). One respondent had a moderate level of experience, three respondents were at the advanced level and the remaining three had an expert level of experience. The next question asked the respondents to state their level of experience in spatial planning or architecture on a range from 1 (none) to 5 (it is my profession). Two respondents selected number 1 (no experience), three respondents selected number 2 (basic experience), one respondent selected number 4 (very good level of understanding of the field) and one respondent selected number 5 (a professional spatial planner). These responses suggest that a considerable amount of experience with Cities: Skylines is required to participate in a design contest, but on the other hand, the required level of experience in spatial planning or related fields can be fairly low.

In 10^{th} question, the respondents were asked to select their age group. All respondents selected the age group 17-25. The final question provided space to submit an additional comment about the VOP Velkomoravská design contest or, in general, regarding the use of Cities: Skylines for designing real-world places. Three comments were submitted. The first comment suggested extending the time for creating and submitting designs. Extending the time would allow for more designs to be submitted as well as allow the players to increase the quality of the designs. In the second comment, the respondent liked the idea of using Cities: Skylines for designing a real-world place and the fact that the design contest was open to anyone. The last comment suggested that even though Cities: Skylines has too many limitations to be used as a professional city planning tool, the game can be useful for observing traffic patterns and visualizing designs.

Jury's feedback

Feedback from the members of the jury was gathered during the assessment of the designs and then later with an additional short questionnaire. The provided feedback refers to the designs, the design contest, and the general use of Cities: Skylines in spatial planning.

Ing. Arch. Petra Růžičková, the representative of the city of Olomouc, pointed out that the street Velkomoravská is, according to the city's masterplan, planned to be changed from a higher speed road to an urban road with easy access to shops and residential housing. This condition was omitted from the contest design rules. Therefore, the designs that treated the street Velkomoravská as a barrier were at a disadvantage. This error happened during the preparation of the design rules. In an attempt to simplify the rules by selecting the most important conditions from the masterplan, the development plans for the street Velkomoravská were not included. This valuable feedback shows the importance of preparing the design rules. The rules should be created in consultation with the city representatives or, ideally, created by the city representatives themselves.

Ms. Růžičková appreciated designs which worked with the river Morava as an important element in the area. Even though the city's masterplan requires only sufficient flood protecting measures, the riverbank is an ideal place for recreation and as such deserves special attention in the design.

The use of large parking lots (especially in areas of high housing density) in some of the designs is not a common practice in current urban planning in the Czech Republic. The use of parking houses and underground parking is preferred.

Situating the housing into blocks (designs by Piňos/Hrabánek, Silvaret, Niko Eriksson) is a good option and corresponds with the latest trends. On the other hand, the blocks should be open, allowing throughgoing pedestrian traffic. Closed housing blocks act as a barrier.

The use of dead-end streets (cul-de-sacs) does not fit the central European style of urban planning.

Silvaret's design with a sports hall presented a compelling idea, but to be considered professionally, the design would require added detail, especially regarding parking and access for thousands of people coming to or leaving an event.

Other mentioned advantages of the designs or in general the gaming approach:

- The presented designs included more public space and services than required by the master plan, which creates a more pleasant environment for the inhabitants.
- Some of the designs created a local centre with shops, services, or parks, where a neighbourhood events can be held.
- The game simulates the authentic behaviour of the inhabitants (going to work, school, shops) instead of randomly moving them from place to place to create a dynamic effect. The game simulations help one to recognize the relations in the design.
- First person camera view presented a valuable insight into the design.
- Creating designs in Cities: Skylines (or a similar game) is good for inspiration, for understanding relations within and outside the design and for finding issues.

Furthermore, a short questionnaire was sent to all members of the jury. The survey had 7 questions where questions 1 to 6 were in the form of a statement. The responses to questions 1 to 6 were ranked on a scale from 1 (strongly disagree) to 5 (strongly agree). Table 11 summarizes the responses to questions 1 to 6.

Table 11 Responses of the jury members to the questionnaire's statements.

Statement	Jiří Pánek	Jaroslav Burian	Pavla Hluštíková	Petra Růžicková
The rules of the design contest were sufficient.	2	4	5	2
The form of video presentation of the designs was sufficient.	4	3	4	4
The game Cities: Skylines can be used as a professional tool for creating designs.	4	4	2	2
The game Cities: Skylines can be used for inspirational thinking (i.e. brainstorming).	5	5	4	3
The game Cities: Skylines can be used for presenting a design of planned developments to the public.	5	5	3	3
The game Cities: Skylines can be used to include the public into the decision processes of spatial planning (i.e. participation)	3	5	3	3

At the end of the questionnaire, a space for a comment was added. Both Mr. Burian and Mr. Pánek commented on the fact that the designs were difficult to compare (even with the unified video format). Mr. Pánek further suggested adding the budget and expected population as assessment criteria.

The received responses suggest that the design rules were not sufficient. In contrast, as mentioned above, some of the players found the rules strict. This again points out the need, whilst creating the rules, to find the fine line between setting professional conditions that allow good comparison, and playful conditions that attract players to participate in the contest.

As for the use of Cities: Skylines in spatial planning, the respondents see the game's biggest potential in being used as a tool for inspirational and critical thinking. The respondents see the other uses as conceivable but with some limitations.

8.1.6 Summary of the VOP Velkomoravská design contest

In total 11 designs of a new neighbourhood were submitted for the VOP Velkomoravská design contest. Overall, the interest in the design contest was higher than expected. The designs demonstrated a wide range of innovative ideas and different approaches to spatial planning, which was appreciated by the jury. According to the questionnaire, most of the players do not have expertise in spatial planning or similar fields such as GIS. Despite this fact, they were able to use the game model to plan and develop a whole new neighbourhood with all its relations. In this case study, the game served as a tool of geo-participation. A description of the design contest was published in a local magazine and the web portal of the city of Olomouc (*Možnou Budoucí Podobu Nové Olomoucké Čtvrti Navrhovali Hráči z Celého Světa*, 2021; *Studenti ve Hře Řešili Návrh Nové Čtvrti Na Velkomoravské*, 2021).

8.2 Traffic simulations in the modelled city

To further explore the possibilities of the application of city-building games in spatial planning, the second case study used the model of Olomouc as a simulation tool. The game Cities: Skylines offers numerous city-related simulations, from noise pollution, to electricity consumption, to citizen happiness. The traffic simulations present the very core of the game simulation engine, affecting almost everything happening in the model. Therefore, in this case study the focus was given to selected traffic simulations in the created model of Olomouc.

First, the traffic congestion of the road network was simulated in the whole city model. Traffic density was observed in standard playing conditions as well as in simulated morning and afternoon traffic peaks. Beside visual observation, the simulation results were exported into a text file. The results of the simulated traffic congestion were compared to data obtained from the HERE Traffic API. By comparing the simulation results with authentic traffic data, an evaluation of the game's simulation accuracy was completed.

Additionally, using the game's features, the model of Olomouc was modified in order to model the following traffic scenarios:

- demolishing a part of a road network (e.g. a bridge)
- building a highway bypass connecting arterial roads D/35, I/55 and I/46

The behaviour of the modelled agents was observed and described for each scenario.

8.2.1 Traffic simulation in Cities: Skylines

Before Cities: Skylines, the development studio Colossal Order released a game, Cities in Motion, which focused on managing traffic and transportation in pre-built cities. Parts of the simulation logic were later incorporated into Cities: Skylines as well. Using Cities: Skylines' Road Tool, the player can construct roads of various types and shapes. A game road consists of segments and nodes that create a complex interconnected topological network. Inhabitants of the modelled city then utilize the road network to travel to work, school, shops, etc. The game individually tracks the passage of every citizen's vehicle as well as service and freight vehicles. In the traffic info view, the player can observe the traffic flow of each road and identify problematic parts of the road system. Figure 59 presents an example of an info view displaying the traffic congestion in the modelled city.

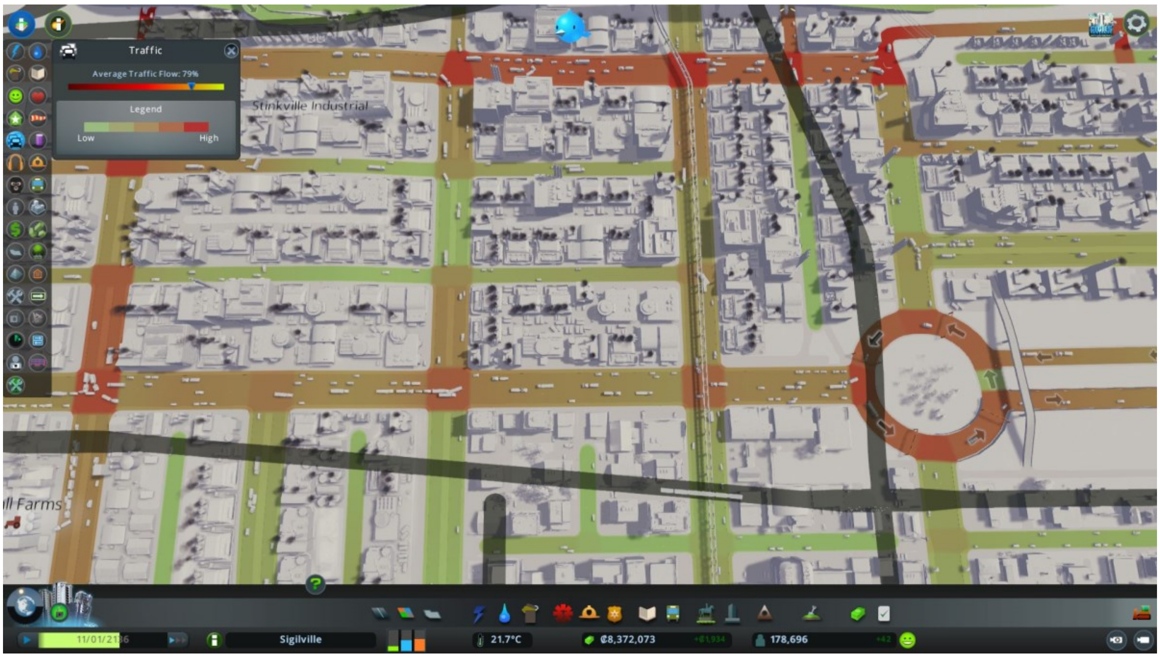

Figure 59 Traffic info view in Cities: Skylines (*Info Views*, 2019).

Each citizen of the virtual city, controlled by an agent, has possible locations they wish to visit. The game takes into account whether the citizen owns a vehicle, the congestion of the roads, and whether public transport is available. According to these factors, the game, using the A* pathfinding algorithm, chooses a means of travel and an appropriate journey path for the citizen (*How Traffic Works in Cities: Skylines*, 2020). There are also simplifications incorporated in the traffic simulation, mostly to prevent heavy computational load and excessive complexity. Some of these simplifications include hard set limits for simulated vehicles, transporting a stuck vehicle to its original destination or remaining on a given route that was originally planned and not recalculating it constantly (Lehto et al., 2015).

8.2.2 Traffic Manager and other traffic mods in Cities: Skylines

There are numerous freely available, Cities: Skylines mods which enhance the default possibilities of the game's traffic simulation. The mod *Network Extensions* extends the list of road types that can be used in the game. The mod *Roundabout Builder* provides a simple and efficient tool for building a roundabout of any size and road type. The mod *Real Time* enables a realistic change of day and night and modifies the behaviour of the agents accordingly. Using this mod, traffic peaks can be observed in the modelled road system. The essential mod when simulating traffic in Cities: Skylines is the mod *Traffic Manager: President Edition* (TMPE). This mod adds to the game a wide range of tools to control the traffic as well as various enhancements to the simulation logic (*TM:PE V11 STABLE*, 2020).

The tools allow the player to toggle traffic lights at a junction, configure a set of steps for a traffic light, control the lane transition, set priority roads and give way signs, set junction rules, set speed limits and vehicle restrictions on roads or forbid parking. The majority of these tools were used to configure the road network of the Olomouc model. Figure 60 shows an example use of the TMPE tools.

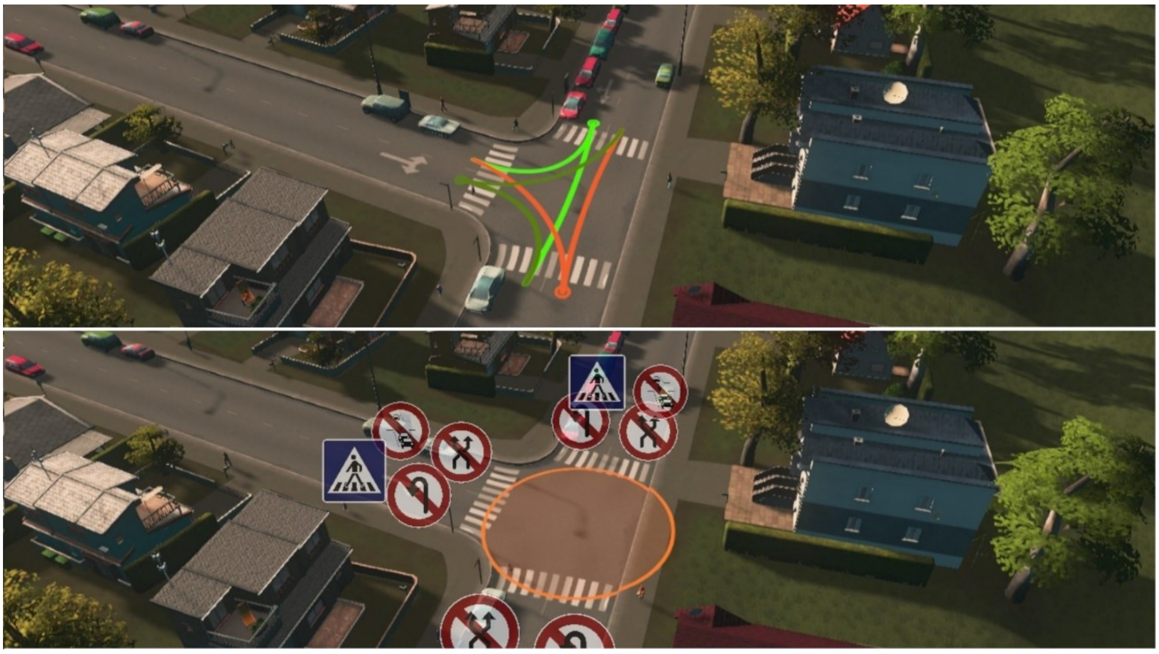

Figure 60 Using TMPE, the traffic can be managed e.g. by a lane connector (top) or by setting the junction rules (bottom).

In addition to the added tools, TMPE also enhances the game's traffic simulation logic to increase the simulation realism. The enhancement options – which can be turned on or off in the mod's menu - include an improved pathfinding cost calculation scheme, a lane selection algorithm allowing switching to an alternative lane while en route, and enforcing parking by disallowing "pocket cars" (a situation when a car appears from nowhere for a citizen who is starting a trip) (*Traffic Manager: President Edition Documentation*, 2019).

Full source code of the TMPE mod is available on the platform GitHub where the whole project can be forked and then further modified (Philipp, 2019). This option can be used for projects or study cases focused on a particular traffic problem.

8.2.3 Update of the model of Olomouc

Before observing any traffic patterns, the model of Olomouc required an update to remove or mitigate any issues affecting the traffic simulations. The basic updates included:

- fixing disconnected roads
- fixing bad road connections (e.g. due to small segments connecting)
- widening big intersections with the mod *Node Controller*
- preventing heavy transit traffic in the historic centre by:
  - banning transport trucks from the city centre by applying the policy 'Heavy traffic ban' in the district 'Hist Centrum'
  - changing the type of roads entering the squares in the historic centre (e.g. Pavelčákova) to type 'Zonable Pedestrian Paved Tiny Road' (on this type of road cars must give way to pedestrians)
  - changing speed limits of the roads in the historic center to 20 km/h
- building a zoo at Svatý Kopeček to attract tourists

Furthermore, the capacity of buses and trams were extended using the mod *Improved Public Transport 2* (*Improved Public Transport 2*, 2020). By default, the bus in the game has the capacity for 30 passengers and the tram 90 (three wagons, 30 per wagon). In reality, the city of Olomouc predominantly uses Solaris 12 buses, which can have a maximum capacity of 104 passengers. On the other hand, reaching the maximum capacity rarely happens and thus the bus capacity in the game was extended to a middle value of 60. Similarly, the tram capacity was extended from 90 to 120. Additionally, the number of vehicles was reduced if there were too many for a particular transport line.

Next, numerous updates of the road network were completed using the TMPE mod. Using the lane arrow tool and the lane connector, a proper lane transition on roads was enforced (e.g. removing the options to turn where there should not be any turns). By setting the junction rules, all incorrectly generated pedestrian crossings were removed. All roundabouts were updated to properly handle traffic (in the original version of the game, the roundabouts display problematic traffic patterns). Selected major roads in Olomouc were marked as main roads. This action set the give way rule of the connected side streets accordingly. Next, a loop of steps was set for most of the junctions with traffic lights using the timed traffic lights tool. Timed traffic lights present a significant improvement to the simulation compared to a junction with standard traffic lights. Figure 61 shows the comparison of a junction with standard traffic lights (left) and a junction with timed traffic lights (right). In a junction with a standard traffic lights, the path of the vehicles turning left collide with the path of those going straight in the opposite direction. This path collision causes the vehicles to slow down or stop completely until the path is cleared. The stopped vehicles then affect the other vehicles and so on. At a junction with a timed traffic lights, a step just for left turning cars can be added. This way the traffic at the junction flows better.

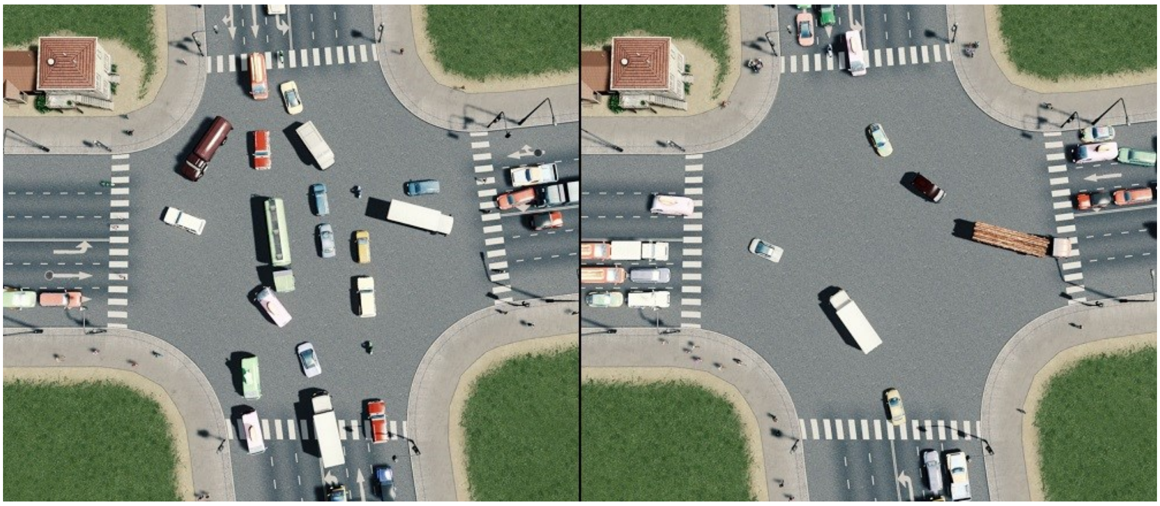

Figure 61 The use of timed traffic lights in Cities: Skylines. On the left, a junction with standard traffic lights. On the right, the same junction with timed traffic lights.

As for modifying the simulation logic, the options of the TMPE mod were set as follows:

- Simulation accuracy: Medium
- Reckless drivers' percentage: Minor Complaints (2%)
- Enable Advanced Vehicle AI
- Dynamic lane selection: 20%

The naming of the option '*Simulation accuracy*' might be misleading as it does not affect the overall traffic simulation. This option sets how many vehicles at junctions are considered for calculations with priority signs or timed traffic lights. The option '*Reckless driving*' introduces various types of violation of the traffic rules. The option '*Enable Advanced Vehicle AI*' enhances the path-finding algorithm, lets vehicles choose the route based on the current traffic situation and improves the overall lane usage. By default, when a route is calculated in the game, the route, including the lane selection, stays static. The option '*Dynamic lane selection*' introduces real-time adaptations for the calculated route. The setting of this option specifies the percentage of vehicles performing a dynamic lane selection (*Traffic Manager: President Edition Documentation*, 2019).

The TMPE mod offers more options to make the traffic simulations more realistic, however these options do not forgive any unrealistic setting of the road network in the model. E.g. the option to '*Enable more realistic parking*' enforces parking which prevents situations when a vehicle is spawned out of nowhere for a citizen who is about to start a trip (these situations are often referred to as "pocket cars"). However, if the model does not include enough parking spaces within the city, the citizens will be forced to find parking spaces at the outskirts of the city, or even in the surrounding villages, increasing the overall traffic along the way. When TMPE is configured for the most realism, the traffic in a model that is not perfectly configured will increase significantly.

The scope of this research did not allow for further updates of the model (e.g. recreating adequate amount of parking spaces would require collecting and pre-processing an additional geographical dataset), therefore the research continued with the current model of Olomouc and the TMPE simulation settings mentioned above.

Last, the mod Real Time was installed (*Real Time*, 2020). In the original version of Cities: Skylines, the time is sped up significantly. The mod Real Time changes the time flow to mimic the actual time. The change of day and night then feels more natural (day/night shifts in the game take around 2 hours of real time instead of 10 minutes of the original version of the game). The aging of the citizens is slowed down as well. Furthermore, with the use of this mod, the citizens travel to work or school in the morning, return home in the afternoon and sleep at night. This behaviour creates traffic patterns known as rush hours.

8.2.4 SegmentMonitor mod

In order to monitor the traffic in Cities: Skylines, I created the mod SegmentMonitor. This mod is included in appendix 5. The main class of this mod, SegmentMonitorThreading, inherits from game's API class ThreadingExtensionBase. Using the inherited method OnUpdate(), which is triggered at every simulation step, the mod exports the traffic usage of segments in the game into a CSV file. The export is done every 15 minutes of the game time (using the Real Time mod is highly recommended) and added to the CSV file. The usage of a segment is taken from the parameter m_trafficDensity that represents the number of cars driving through a segment at the monitored moment. Two exports are done, one for each individual segment and anther one for whole roads (segments are grouped by road name). To prevent extensive logging that slows down the whole game, the segments are filtered based on traffic density and length. Segments that are too short or have small traffic density are filtered out. The mod automatically starts monitoring the segment usage after loading a model and will stop when the model or the game is exited. Figure 62 shows an example of the game's roads usage exported in a CSV file.

	A	B	C	D	E	F	G
1	RoadName	"NumOfSegs"	LengthOfSegs	AvgDens	"DateTime"	"Date"	"Time"
2	Pavlovická	20	924.8246	36.5	9/6/2080 0:22	9/6/2080	12:22:21 AM
3	Hamerská	28	1760.415	31.89286	9/6/2080 0:22	9/6/2080	12:22:21 AM
4	Holická	29	1563.794	43.24138	9/6/2080 0:22	9/6/2080	12:22:21 AM
5	Lipenská	23	1653.973	28.17391	9/6/2080 0:22	9/6/2080	12:22:21 AM
6	Přerovská	31	1741.414	39.19355	9/6/2080 0:22	9/6/2080	12:22:21 AM
7	No Name 72	9	498.9428	28.44444	9/6/2080 0:22	9/6/2080	12:22:21 AM
8	Železniční	13	942.6675	41.92308	9/6/2080 0:22	9/6/2080	12:22:21 AM
9	Na zákopě	19	1041.477	27.68421	9/6/2080 0:22	9/6/2080	12:22:21 AM
10	Šlechtitelů	20	1172.21	28.65	9/6/2080 0:22	9/6/2080	12:22:21 AM
11	Dobrovského	21	1210.169	33.19048	9/6/2080 0:22	9/6/2080	12:22:21 AM
12	No Name 2908	2	143.0535	29.5	9/6/2080 0:22	9/6/2080	12:22:21 AM
13	Wittgensteinova	13	358.5991	47.23077	9/6/2080 0:22	9/6/2080	12:22:21 AM

Figure 62 CSV output of the SegmentMonitor mod.

8.2.5 Monitoring traffic density of the whole model

The aim of the monitoring was to identify the parts of the model's road network with the heaviest traffic. The game's traffic info view provides a visual output of the traffic density. In the model of Olomouc, the overall traffic density ranges between 76% and 82%. Figure 63 shows the visual output of the traffic density in the model of Olomouc.

Figure 63 Traffic info view for the model of Olomouc.

Using the game's traffic info view, problematic parts of the road network can easily be spotted. However, to exactly identify the busiest roads in the model, the road network was monitored using the SegmentMonitor mod.

The model of Olomouc was started in the early morning hours of the game time and was left running for an entire game day. During this time, the mod SegmentMonitor recorded the segment's traffic density every 15 minutes. When the monitoring was finished, the exported file RoadMonitor.csv was opened in MS Excel. The records were sorted by road name which grouped every 15 minutes of monitoring under the same road record. Next, using the function subtotal, a sum of values of the column AvgDens for each road was calculated. The column AvgDens represents average density of the road. It is calculated as a sum of m_trafficDensity of each segment divided by the number of segments of the road. The sum of average density was preferred in this case because the filtering mechanism of the SegmentMonitor mod produces an inconsistent number of road records (i.e. using the average operation would favour roads where the traffic density peaked once over roads where the traffic density is consistently high). Finally, the road name and their subtotals were ordered from highest to lowest to produce the final list. The resulting sum of average density in this case serves only as an indicator of high traffic density. Table 12 lists the 20 busiest roads in the model of Olomouc. Roads without a name are marked with either the game's generated name in English or with the 'No Name' prefix generated by the GeoSkylines mod. In these cases, the column Notes describes the location of the road.

Table 12 20 busiest roads in the model of Olomouc.

Road Name	Sum of AvgDens	Notes
U podjezdu	5678.5	
No Name 4052	4178.9	I/46 near Dolany
Svatoplukova	3906.8	
Hickory Street	3852.7	I/46 near Týneček
Raymond Street	3529	connection from Brněnská to Velkomoravská
Rolsberská	3452.2	
Price Street	3207	roundabout at Dobrovského
No Name 4742	2937.3	roundabout at Týnecká
Holická	2802.1	
Dr. Milady Horákové	2774.3	
Chválkovická	2658	
Pavlovická	2534.9	
Erenburgova	2529.1	

No Name 2908	2434.5	connection from I/46 to an industrial zone near Dolany
Hodolanská	2406.7	
Roháče z Dubé	2355	
Litovelská	2304.9	
Wittgensteinova	2057.6	
Lipenská	2038.9	

According to the simulation, the busiest parts of the model's road network are near the industrial areas in districts Bělidla and Pavlovičky. The roads U podjezdu and Chválkovická serve as a connection to the industrial zones as well as an exit road from the city. Additionally, the simulation identifies roundabouts and some connections as roads with a high traffic density, mostly due to cars driving slowly through these road network elements. The table above predominantly lists roads at the outskirts of the city of Olomouc or completely outside of it (e.g. parts of the I/46 road). To find out the busiest roads within the inner parts of the city, the roads were filtered using the boundary displayed in Figure 64.

Figure 64 Boundary of the inner city of Olomouc used to identify the busiest roads within the city.

Table 13 lists the 15 busiest roads within the specified boundary of the inner city of Olomouc.

Table 13 15 busiest roads within the specified boundary of the inner city.

Road Name	Sum of AvgDens
Dr. Milady Horákové	2774.31583
Litovelská	2304.99999
Wittgensteinova	2057.6923
Gorazdovo nám.	2023.75
Velkomoravská	1796.69118
Pasteurova	1586.27271
kpt. Nálepky	1433.8
Dobrovského	1108.57144
17. listopadu	870.05555
Na střelnici	776.23075
Studentská	766.66666
Palackého	580.5
tř. Svobody	548.76471
Sokolská	402.69229

8.2.6 Monitoring authentic traffic data

In order to compare the simulated traffic data from the model of Olomouc to the real traffic situation in the Olomouc area, authentic traffic data were monitored using the HERE Traffic API. The HERE Traffic API is a REST API which provides information about traffic flow and incidents on the roads (*HERE Traffic API*, 2021). The API is called via URL request with the parameters *apiKey*, *bbox* and *responseattributes*. For the parameter *apiKey* I used my personal API key generated on the HERE Developers platform. The parameter *bbox* is a spatial filter of the request. It represents a rectangular area specified by two latitude/longitude pairs (the top-left corner and the bottom-right corner of the bounding box). The same bounding box which was used for recreating the Olomouc area in Cities: Skylines was also used for requesting the authentic traffic data. The parameter *responseattributes* was set to 'shape'. This way the response provided a list of latitude and longitude coordinates defining the geometry of the roads as well. The response is a structured XML file containing roads from the specified bounding box and their attributes. The most important attributes for this research were *DE*, which is the text description of the road; *PBT,* which is the time when the traffic data were recorded; and *JF,* which is a number between 0 and 10 indicating the expected quality of travel, with 10 being the most obstructed.

I developed a Python script to convert the received XML file into a GeoPackage layer (using the GDAL library). The developed script is included in appendix 6. This script creates the road records, creates the line geometry from collected latitude and longitude coordinates, renames the attributes (e.g. JF to Jam_Factor) and stores the attribute values. Additionally, the Python script includes a mechanism to call the API request repeatedly in a specified time interval.

The traffic data were monitored on Thursday 1st of October 2020. The Python script was started on 30th of September 2020 after 10pm and kept running through late night hours of 1st of October 2020, requesting data from HERE Traffic API every 15 minutes. The collected data were later filtered to include only records from the time frame 1st of October 5 am to 1st of October 9pm. For this task, the time from the attribute *PBT* was considered and not the time when the request was called. Each request created a new layer in the GeoPackage dataset. To further analyse this data, all layers were merged into one. An additional attribute *time* was created to store the value of the attribute *PBT* in a more suitable format. Using QGIS and the plugin TimeManager, a time animation was created to identify the traffic patterns in the road network of the city of Olomouc. Figure 65 shows four frames from the animation presenting the morning rush hour, the calmer traffic around 10 am, the 2nd rush hour around 1:30 pm and the calm traffic in the evening hours. Note that the road Masarykova třída remains red even when the traffic is calm. This issue was caused by major reconstruction work being carried out on this road. For this reason, the streets Masarykova třída and 1. máje were excluded from the comparison.

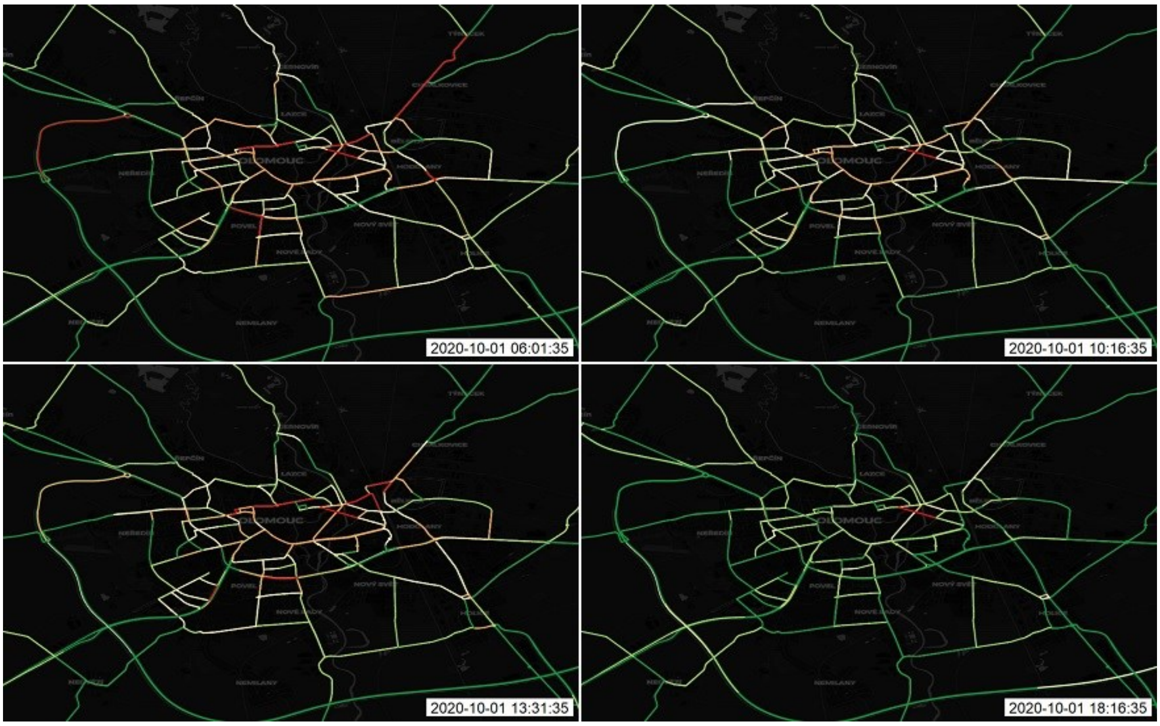

Figure 65 Authentic traffic in Olomouc on 1st of October 2020.

To find the busiest roads, the merged GeoPackage layer was exported into a CSV file. After opening the CSV file in MS Excel, the data were ordered by the attribute *Road_Description*. Next, using the subtotal function, an average of values of the attribute *Jam_Factor* was calculated for each road. Finally, the road name and their subtotals were ordered from highest to lowest to produce the final list. Table 14 lists the roads with the highest *Jam_Factor* (roads affected by the construction work near street Masarykova třída were excluded).

Table 14 20 busiest roads according to monitoring of authentic traffic in Olomouc on 1st of October 2020.

Rank	Jam_Factor	Road_Description
1	3.11	Studentská
2	3.06	tr. Svobody
3	3.02	Komenského
4	2.87	17. listopadu
5	2.75	Husova
6	2.71	Pavlovická
7	2.70	Palackého
8	2.54	Legionárská
9	2.46	Hynaisova
10	2.46	tr. Kosmonautu
11	2.37	Hodolanská

12	2.20	tr. Svornosti
13	2.18	Foerstrova
14	2.15	Brunclíkova
15	2.14	U podjezdu
16	2.11	Havlíckova
17	2.11	Hranicní
18	2.07	Premysla Oráce
19	2.02	Dobrovského
20	2.01	Dr. Milady Horákové

The majority of the roads in the dataset obtained from HERE Traffic API are represented by two or more road parts. Grouping these parts under the road name might unintentionally hide traffic issues of the road network. E.g. for a long road which includes a part with a high traffic density and other parts with a low traffic density, the calculated average will hide the problematic part of the road. Therefore, subtotals were calculated for road records identified by the attribute *fid*. Table 15 lists 20 road records with the highest average *Jam_Factor*.

Table 15 20 busiest road parts according to monitoring of authentic traffic in Olomouc on 1st of October 2020.

Rank	fid	Jam_Factor	Road_Description
1	202	5.27	tr. Svobody
2	521	4.45	Pavlovická
3	267	4.25	Studentská
4	275	4.01	Komenského
5	111	3.85	17. listopadu
6	316	3.82	Foerstrova
7	274	3.59	Komenského
8	677	3.56	I/46
9	203	3.46	tr. Svobody
10	514	3.45	Brnenská
11	266	3.44	Studentská
12	20	3.43	II/446
13	678	3.33	I/46
14	289	3.31	Pasteurova
15	270	3.25	Komenského
16	320	3.22	Tovární
17	283	3.22	Dobrovského
18	303	3.18	Foerstrova
19	207	3.17	tr. Svobody

20	273	3.17	Komenského

8.2.7 Comparison of the simulated and authentic traffic data

The traffic density measured in the game and the jam factor provided from the HERE Traffic API are calculated differently. Additionally, the roads are represented differently in both systems. Therefore, the comparison cannot be absolute. Nevertheless, monitoring of the traffic data provided a general idea of the most problematic parts of the road network in both systems. The figures below offer a visual comparison of the traffic density in the simulated data (Figure 66) and the authentic traffic data (Figure 67). In both cases, the function Natural Breaks (Jenks) was used to set the range of the monitored attribute.

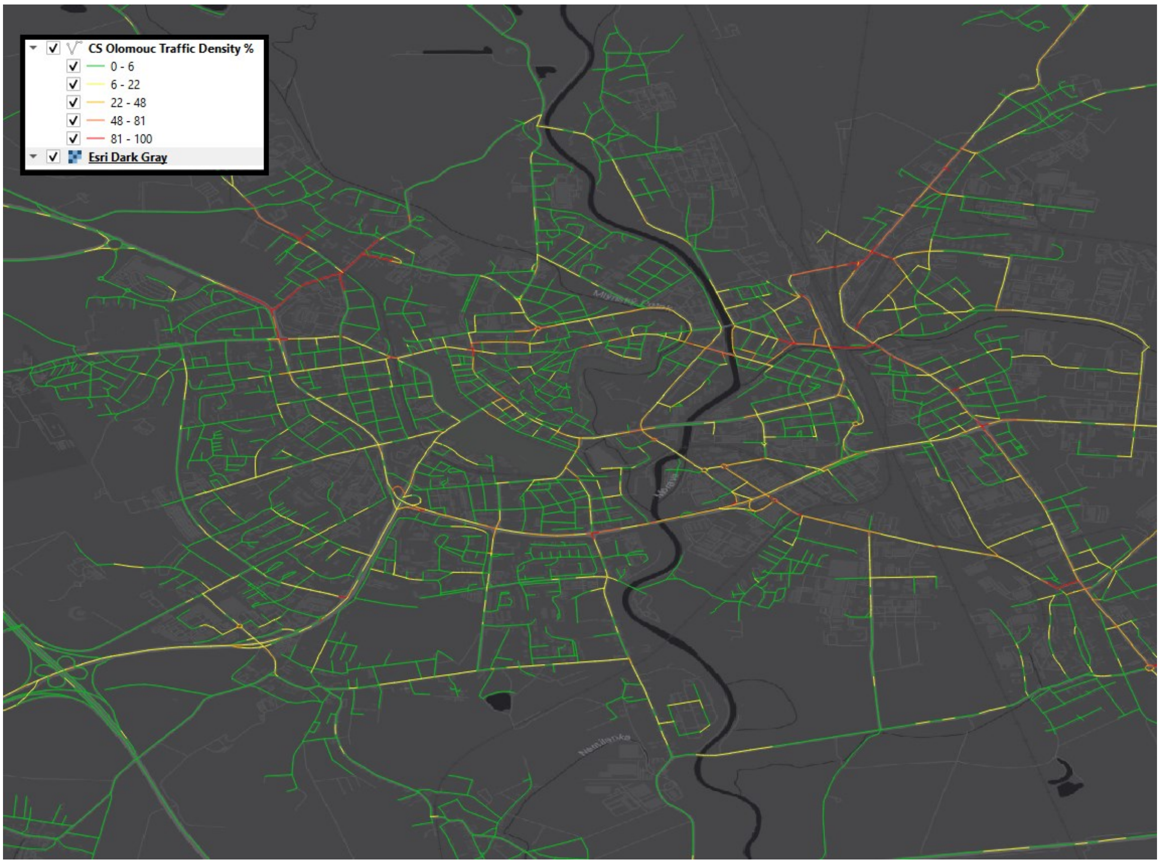

Figure 66 Roads, exported from the model of Olomouc and imported into QGIS, and their traffic density.

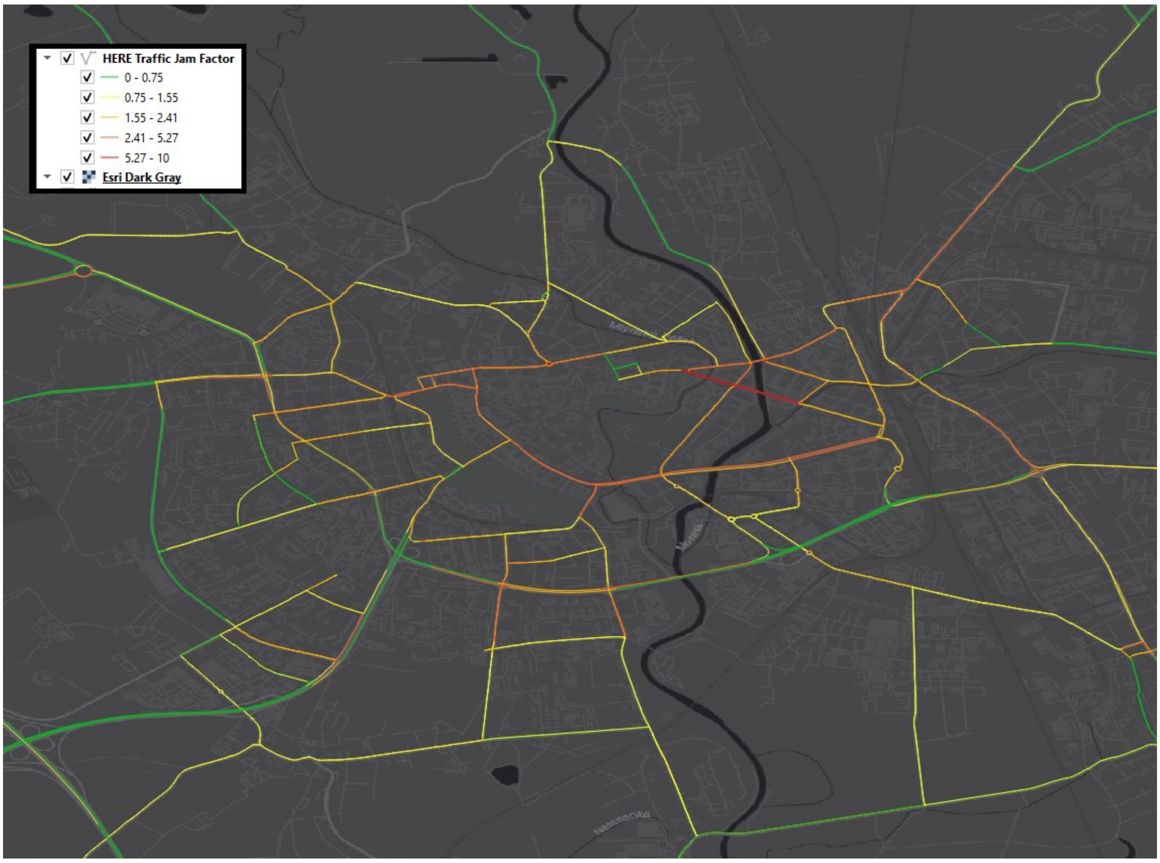

Figure 67 Roads of Olomouc and their jam factor according to HERE Traffic API, monitored on 1st of October 2020.

Even via a simple visual comparison, we can see that both the simulated and the authentic traffic data identify similar issues of the road network: the roads near industrial zones in the districts Bělidla and Pavlovičky (Hodolanská, Pavlovická, Chválkovická, U Podjezdu, Roháče z Dubé), the intersection of Lipenská and Tovární, the main roads in the district Holice (Rolsberská and Přerovská) and the high speed road Velkomoravská. However, the model simulates higher traffic on roads Erenburgova, Svatoplukova and Dr. Milady Horákové than the authentic traffic data suggest. On the other hand, the model simulates lower traffic on roads Studentská, tř. Svobody and Kosmonautů.

The comparison of Table 12 and Table 14 provides more detail. The busiest roads according to the authentic traffic data (such as Studentská, tř. Svobody or tř. 17 listopadu) are not recognized by the simulation as the busiest. The busiest roads according to the simulation are often roads that serve as a connection to industrial zones (U podjezdu, Roháče z Dubé, Svatoplukova). This simulation result is likely caused by the game's exaggerated demand for supplies for the industrial zones. The high demand then generates a high number of freight vehicles. To mitigate this behaviour, the industrial zones can be made smaller in the model.

Other inaccuracies of the simulation might be caused by imperfections of the model or the nature of the agents (i.e. perfect driving without accidents). For example, in the model, vehicles heavily use the road Dr. Milady Horákové while in reality many drivers see this road as problematic and try to avoid it (though it is still used considerably). The factor creating the difference in this case might in fact be minor: while a complicated connection from Masarykova třída and the narrowness of the road prevents some drivers from taking this road, the simulated vehicles, not fearing any accidents, see this road as any other road and decide to take it.

The inaccuracies of the traffic simulation can be mitigated by updating the model. In the case of the road Dr. Milady Horákové, the speed limit can be lowered on this road. The agents will then start favouring other routes. This effect was tested when configuring the model of Olomouc for the traffic simulations. Initially, the traffic in the historic centre was quite high as the roads were seen by the agents as standard roads which often provided the shortest path to their destination. However, simply adding speed limits, the agents started favouring other roads and thus the heavy transit traffic was prevented.

8.2.8 Simulating traffic scenarios

Aside from simulating the traffic density in the whole model of Olomouc, two scenarios were tested as well. The first scenario - demolishing a bridge connecting the roads Komenského and Pasteurova – represents the real reconstruction that this bridge underwent in 2019 and 2020. This bridge is an important part of a route navigating the traffic out of the city centre to Pavlovičky and then outside the city of Olomouc. The second scenario – constructing a highway bypass connecting arterial roads D/55, D/35 and I/46 – represents a planned development in this area (*Silnice I/46 Olomouc – Východní Tangenta*, 2021; *Silnice I/46 Týneček – Šternberk*, 2021).

Demolishing a bridge connecting roads Komenského and Pasteurova

In a stabilized state of the traffic simulation, the simulation was stopped, and the bridge connecting roads Komenského and Pasteurova was removed from the road network using the game's bulldoze option. The simulation was then started and left running for several minutes for the game to recalculate the routes. Figure 68 shows the stabilized states of the traffic simulation before demolishing the bridge (top) and after demolishing the bridge (bottom).

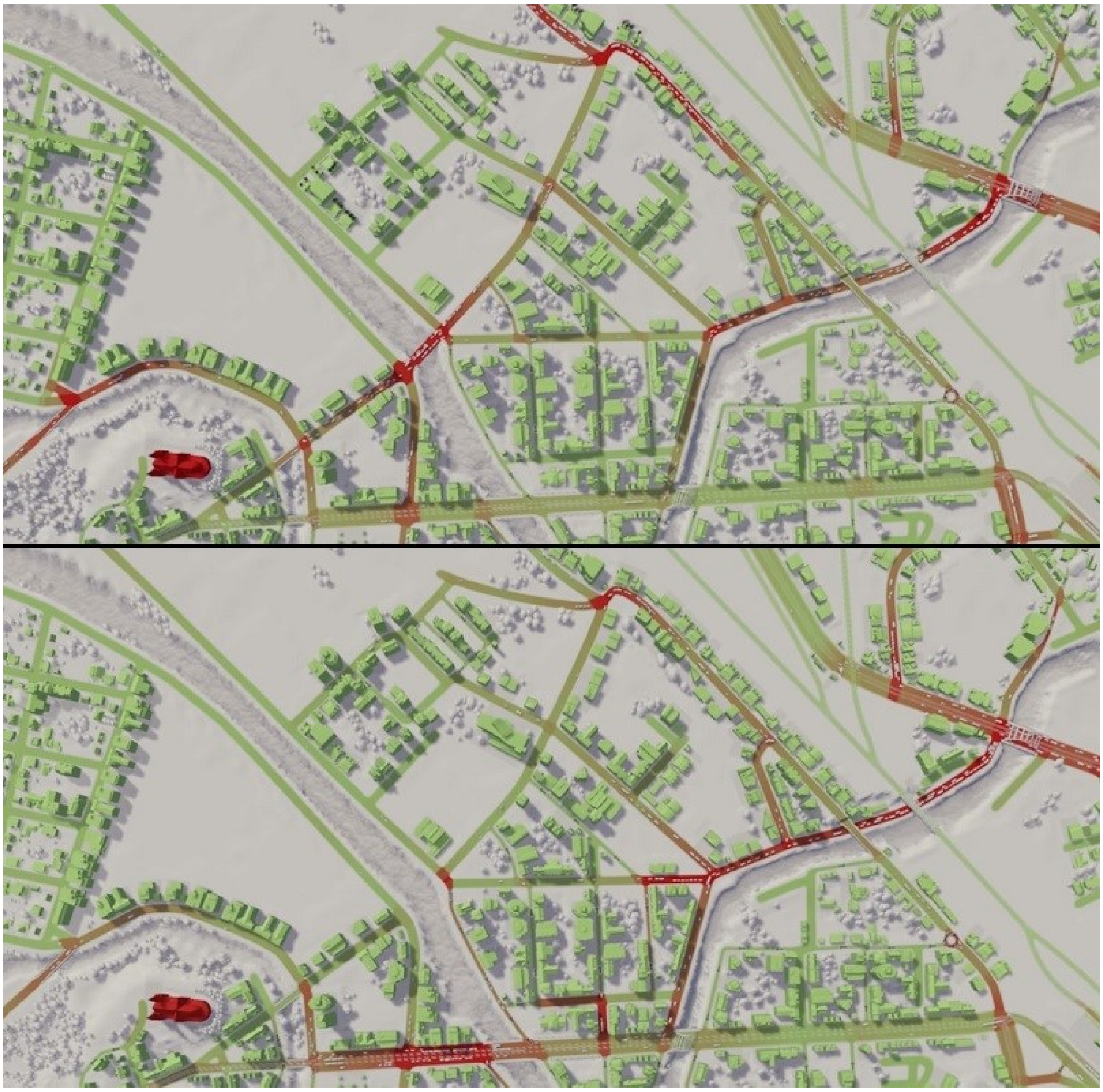

Figure 68 Traffic info view before demolishing the bridge (top) and after demolishing the bridge (bottom).

The traffic density increased significantly on the roads Dr. Milady Horákové - from 45.5% to 59.7% - which serves as a connection to the road Pavlovická (access to industrial zones and exit from the city) and Masarykova třída – from 8.9% to 30% - which became the only exit road from the historic centre. The traffic density increased also on a small road Jiřího z Poděbrad – from 22.6% to 29% - which redirects most of the traffic from the road Dobrovského. Some cars tried to utilize side roads such as Nábřeží – from 3.7% to 24.7% - and Kaštanová – from 9.4% to 12.7% - which connects roads Dr. Milady Horákové and Pasteurova (leads to U podjezdu and Chválkovická).

Constructing a highway bypass

Ředitelství silnic a dálnic ČR (a state organization managing the state's road network) is planning to connect the arterial roads I/55, D/35 and I/46 in two phases. The first development is the creation of a highway bypass which starts at the interchange of roads I/55 and D/35 and then continues around the east side of the city of Olomouc and finishes at a planned interchange near Týneček (*Silnice I/46 Olomouc – Východní Tangenta*, 2021). The second development continues the highway alongside the existing road I/46 from Týneček to Bělkovice-Lašťany where the highway reconnects to I/46 (*Silnice I/46 Týneček – Šternberk*, 2021). The main goal of the developments is to redirect the transit traffic coming from I/55 and D/35 going to Šternberk and then continuing further north. At this moment the transit traffic is travels through local city roads - Přerovská, Rolsberská, Hodolanská, Pavlovická and Chválkovická – increasing the pollution and noise pollution in the city parts Holice, Hodolany, Bělidla and Pavlovičky.

The highway bypass as well as the connecting local roads were created in the game according to the published plans by Ředitelství silnic a dálnic ČR. To create the required road network, the game's Road tool and the mods *Fine Road Anarchy* and *Move It* were used. Figure 69 shows the main interchanges of the created highway bypass. Panel A shows the interchange near Holice (referred to in the plans as ‚MÚK Keplerova'). Panel B shows the interchange near Hodolany (‚MÚK Lipenská') which connects with the arterial road D/35. Panel C shows the interchange near Pavlovičky (‚MÚK Severní spoj'). The local roads displayed in panel C also serve as a connection between Pavlovičky and the villages Samotišky and Sv. Kopeček. The current connection via city neighborhood Chválkovice will be interrupted by the highway bypass. Panel D shows the interchange near Týneček where the road I/46 connects ('MÚK Týneček').

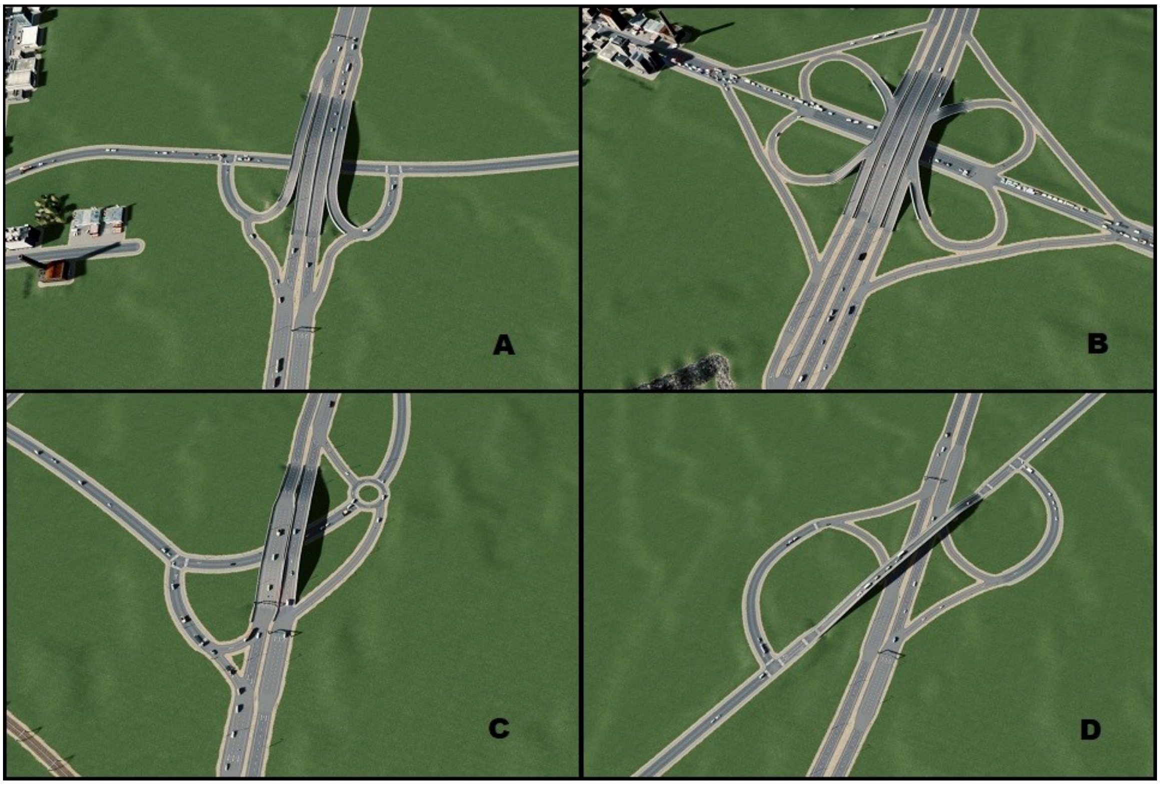

Figure 69 Recreated interchanges of the planned highway bypass: MÚK Keplerova (A), MÚK Lipenská (B), MÚK Severní spoj (C) and MÚK Týneček (D).

After recreating the highway bypass according to the planned developments, the simulation was left running for several minutes for the game to recalculate the routes. Figure 70 shows the stabilized states of the traffic simulation before constructing the highway bypass (left) and after constructing the highway bypass (right). To achieve the best comparison, the function Equal Interval was used to set the range of the monitored attribute for both datasets.

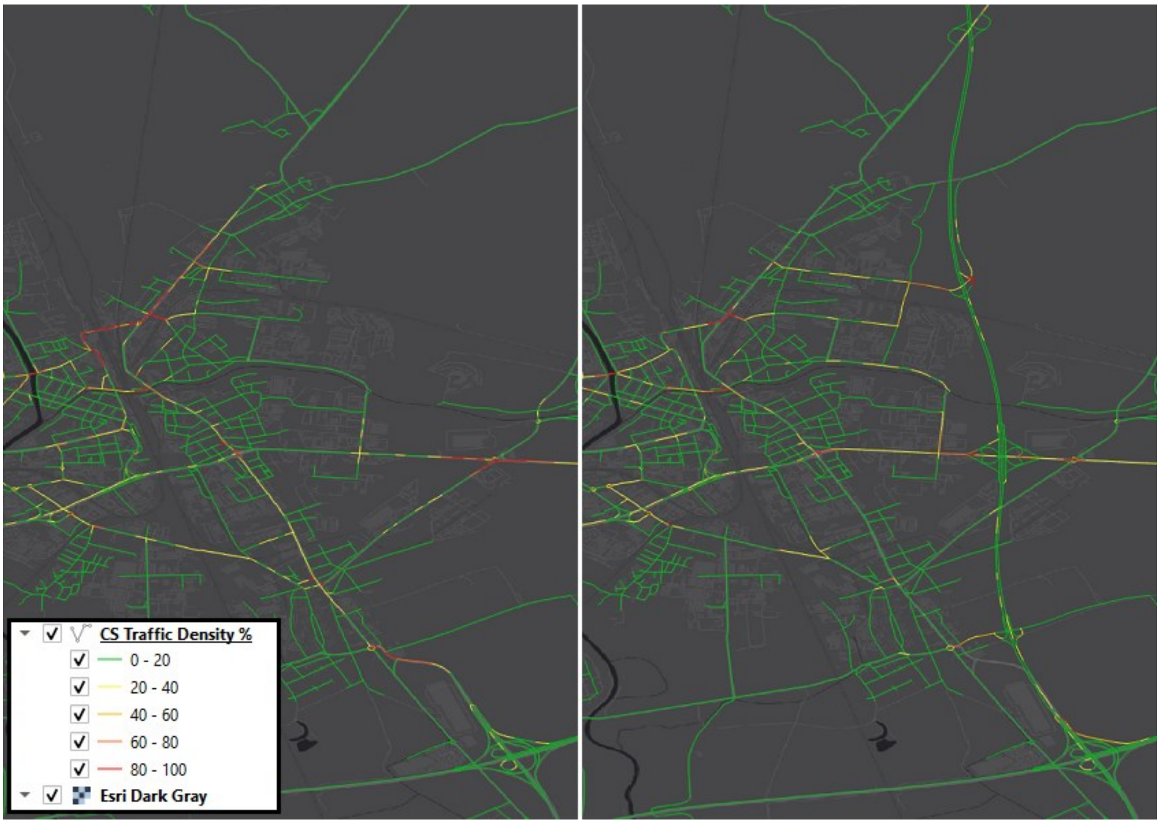

Figure 70 Comparison of roads, exported from the model of Olomouc and imported to QGIS, and their traffic density before (left) and after (right) constructing the highway bypass.

The absolute values of the traffic density were monitored as well. Table 16 presents the comparison of measured traffic density of selected roads before and after the creation of the highway bypass.

Table 16 Traffic density of selected roads before and after constructing the highway bypass.

Road name	**Traffic density %**		
	Without bypass	With bypass	Change %
Přerovská	26.8	12	-55
Rolsberská	50.1	18.7	-63
Hodolanská	37	28.7	-22
Pavlovická	38.9	19	-51
Chválkovická	43.8	14.5	-67
Lipenská	32.4	44.2	+36
U podjezdu	87	63	-28

The traffic density decreased on all the selected roads with the exception of the road Lipenská. This road, after the construction of the highway bypass and the cloverleaf interchange MÚK Lipenská, navigates the freight vehicles to industrial zones in the districts Holice and Bělidla. This comparison suggests that constructing the highway bypass will have a positive effect on transit traffic.

8.2.9 Summary of traffic simulations

In this case study, the traffic simulations provided by Cities: Skylines were tested on the model of Olomouc. Before conducting the traffic simulations, the model was first updated by removing traffic obstacles (e.g. incorrectly generated junctions), by adding traffic rules using the TMPE mod (setting give way signs, timed traffic lights, etc.), by configuring the public transport using the Improved Public Transport 2 mod and by adding new elements such the zoo. Next, the traffic density was monitored in the model – visually as well as using the newly developed mod SegmentMonitor. Authentic data using the HERE Traffic API was monitored as well. Monitoring of both authentic and simulated traffic data pointed out similar problematic parts of the Olomouc' road network. However, it also became apparent that in the model, the traffic density is much higher in areas near industrial zones. This behaviour is most likely caused by an exaggerated demand within the game for services, which then generates a high number of freight vehicles. After monitoring the whole model, the traffic density was additionally monitored in two scenarios: demolishing a bridge and constructing a highway bypass. In both cases, the simulation presented expected results. The second scenario confirmed the benefit of constructing the highway bypass by diverting the transit traffic from the city parts Holice, Hodolany, Bělidla and Pavlovičky.

9. RESULTS

This research provided several results, primary as well as secondary. The primary results are the mod developed for the game Cities: Skylines for processing geographical data, the model of the city of Olomouc in the game Cities: Skylines and the outcomes of two case studies using the created model. The secondary results include an experimental game mod for monitoring traffic density in Cities: Skylines, Python script for monitoring authentic traffic data and a base model of the city of Svit.

9.1 GeoSkylines

As part of Objective 2, a mod for the game Cities: Skylines was developed. This mod has been named GeoSkylines. GeoSkylines offers 15 callable methods for processing geodata. Nine import methods create game objects from the geographical data. These methods create the road network, tree coverage, basins for water resources, railway network, service buildings and zoning. Four export methods output the game objects and save them as geographical data. These methods can export road or railway segments, buildings, zoning, or trees. The mod also includes two methods which provide helpful information, especially for matching geographical object types to game object types.

The GeoSkylines mod processes geographical data in a CSV format. This format was chosen for its ease of use and to prevent possible compatibility issues with the game's ongoing updates. Working with simple CSV files also enables the user to pre-process the geographical data before calling the GeoSkylines methods. For example, unwanted data can be filtered out, the data structure can be modified, or the attribute values can be updated.

The core of all GeoSkylines methods is the conversion from geographical coordinates to game coordinates and vice versa. For storing geodata, WGS 84 was selected as the default coordinate system. On the other hand, the game Cities: Skylines utilizes a custom projected coordinate system that can be considered as a variation of the UTM coordinate system. Therefore, the overall conversion process is based on a standard conversion algorithm between WGS 84 and UTM coordinate systems.

The GeoSkylines mod was published on the platform Steam Workshop (Pinos, 2020b). The mod can be installed into Cities: Skylines by subscribing to it on Steam Workshop. As of May 2021, 291 Cities: Skylines players have subscribed to this mod. Alternatively, the mod's DLL file can be directly added to the game's addons folder. The DLL, the complete source code and the step-by-step documentation is available on GitHub (Pinos, 2020a) and in appendix 1.

9.2 Model of Olomouc

As part of Objective 3, a fully functional model of Olomouc was created in the game Cities: Skylines. The creation of the model was achieved in two main stages:

- Generating the base model of Olomouc using the GeoSkylines methods
- Post-processing the base model to create the resulting playable model of Olomouc

The aim was to create a model that is functional, easy to use and share. The amount of required game mods and custom assets was kept to a minimum. Though achieving visual accuracy was also desired, it was not the main focus whilst creating the model of Olomouc. This is evident most notably for the style of buildings used. The majority of the buildings were automatically generated by the game engine (after setting zoning) from available building styles. A European building style was applied for the historic centre of Olomouc, while remaining residential areas were generated with the game's standard building style.

The model consists of the city of Olomouc and its neighbourhoods (defined as districts within the game) and surrounding villages and small towns. The size of the modelled area corresponds with the size of the gaming area which is 17.28 km x 17.28 km. The centre of the modelled area is located to 17.247812, 49.588705 (longitude, latitude). The modelled area covers the majority of the boundary of the Olomouc municipality, though a small part near town Hlubočky is not included. The population of the whole model is around 110 thousand. The number of created game objects did not exceed the limits of the game. The number of segments (includes roads, pedestrian paths, and railways) is 29,841 out of a maximum of 36,352. The number of created road nodes is 28,948 out of the maximum 32,256. The number of active vehicles is 7,836 out of a maximum of 16,384.

The model, the list of required mods and the list of used custom assets were published on the platform Steam (Pinos, 2020c, 2020e, 2020d). The model is also included in appendix 2.

9.3 Outcomes of case studies

As part of Objective 4, the model of Olomouc was used for two case studies:

- Designing a new neighbourhood in a geo-participation project
- Simulating traffic

The main outcome of the first case study are the submitted designs. Short descriptions and a few screenshots of the designs are included in section 8 of this thesis. Video presentations of the designs were uploaded to the platform YouTube (Brethonière, 2021; Pinos, 2021d, 2021i, 2021j, 2021b, 2021c, 2021e, 2021f, 2021h, 2021g, 2021a). Selected presentation materials of the designs are included in appendix 3. Additional outcomes of the design contest are the design rules, the assessment sheet, and the contestants and the jury questionnaires. All of these items are included in appendix 3.

Outcomes of the traffic simulations include spreadsheets with monitored values and GeoPackage layers of authentic traffic data. The outcomes of the traffic simulations are included in appendix 4.

9.4 Secondary results

An experimental game mod, SegmentMonitor, was developed as part of Objective 4 in order to monitor the traffic density in the whole model in set intervals. The monitored values are exported as a simple CSV file which allow further analysis in programs such as MS Excel. This mod was not published on the Steam platform but is included in appendix 5.

As part of Objective 4, a Python script was developed to efficiently monitor the authentic traffic data. This script sends a URL request to HERE Traffic API and transforms the XML response into a GeoPackage layer (using GDAL library). Additionally, the script includes a mechanism for sending the request repeatedly per given time interval. In this way, the traffic in the city of Olomouc was monitored for the whole day. The Python script is included in appendix 6.

As part of Objective 3, a base model of the city of Svit (Slovakia) was created as a result of testing GeoSkylines import methods. This model is included in appendix 2.

10. DISCUSSION

This section discusses the achieved results of the thesis, the encountered challenges, recommendations, and potential improvements to future research utilizing city-building games in spatial planning.

10.1 Modelling in Cities: Skylines

In Objective 1, the game Cities: Skylines was selected as the game with the highest potential for its application in spatial planning. The reasons why this game was selected were sufficiently validated during the research. Among other useful features of the game, the game's graphic environment, based on Unity 3D, offers vast possibilities for recreating a real-world location. The game's area 17.28 km x 17.28 km x 1 km provided enough space for recreating the city of Olomouc without any spatial distortion. The most important feature of Cities: Skylines is its extensive modding environment, consisting of an API written in C# and the modding documentation (tutorials, user forums, source codes for existing mods, etc.). According to the game publisher, more than 175,970 mods have already been published on the platform Steam (*Cities: Skylines Celebrates Fourth Anniversary and Six Million Copies Sold*, 2019). Numerous mods were used for the creation of the model of Olomouc and for modifying the model's behaviour to achieve the desired results. Moreover, the modding environment was used in this research to develop two new mods for processing geodata and for monitoring traffic density. Without the modding environment, conducting this research would not have been possible.

Nevertheless, the use of the game Cities: Skylines in this research was not always straightforward. The game itself is difficult for new players (after all, the objective of the game is nothing less than to build and manage a city with all its processes). Therefore, very good knowledge of the game is highly recommended when using it in research. The game's biggest strength, the modding environment, can also present a risk if badly managed. Installing various mods, e.g. for enhancing the visual accuracy of the model or for supressing unwanted behaviour, is tempting. But when the number of mods used for a model increases significantly, their management can become very problematic. In the worst-case scenario, when two or more mods modify the same functionality of the game, the model can be corrupted and become unusable. The main tool for managing mods is the platform Steam. A developer uploads his mod to Steam, where other players subscribe to it. Steam then installs the mod into the game and manages further updates. Steam is sufficient for managing individual mods. The problem occurs when managing multiple mods, especially mods conflicting with each other or conflicting with new updates of the game. There are also mods that are no longer functional but are still present on Steam. Due to the problematic presence of these mods on the platform, members of the gaming community maintain a list of obsolete mods that should be avoided. Many modders follow the good practice of including information about conflicting mods in their mod description. Despite the great efforts of the gaming community to help with this problem, the best option would be to include sensible mod management directly into the game. At this moment, there is no official tool for managing mods, thus the user must do this him/herself – properly read the mod description, find out about possible conflicts, decide whether it is really required or not, etc.

As for data processing, uploading terrain into the game via the map editor is the only inbuilt option. To import a road network into the game, the player can install one of a few mods available on Steam. GeoSkylines, the mod developed in this research, enables the import of other geographical data as well (water basins, trees, zoning, etc.). The GeoSkylines mod has been created to provide a standardized way of processing geodata. The mod does not pre-process the geographical datasets. This must be done beforehand by the user (the mod's step-by-step documentation provides examples of data pre-processing). Though this feature decreases the user- friendliness of the mod as it requires some knowledge of GIS, it allows the user to update the datasets before importing them into the game (filtering, renaming attributes or updating attribute values). Alternative mods available on Steam have the processing of OSM road data embedded in them and thus do not allow further changes to the input data.

Numerous challenges occurred during the development of the mod GeoSkylines. Curved geographical roads defined by multiple short narrow segments represented one of the biggest challenges, as importing them into the game created a large number of segments and nodes. Though such generated road network was correctly topologically connected, it caused graphic glitches, unwanted traffic patterns and breached the game limits of created segments and nodes. This issue was resolved by converting majority of the segments into Bézier curves. However, the overall solution had to account for junction nodes and prevent their loss during the conversion process. A challenge that was not resolved during the development of the mod was adding an elevation to the imported roads. Although several attempts were made, none of them presented satisfying results and thus were not included in the final solution. The challenges during the programming of the GeoSkylines mod are described in section 6.7. Despite all of the possibilities that GeoSkylines or similar mods offer, there is undoubtedly still space for improvements for data processing. The ideal scenario which Cities: Skylines, or any other city-building game, should aim for is the example of Minecraft, where a professional data processing tool, FME, can be used for importing and exporting data to or from the game (Boudník, 2020).

Some city-related processes simulated in Cities: Skylines demonstrate unrealistic behaviour. Most notably, this is the case with regard to the exaggerated demand for services. This behaviour was introduced into the game to create a challenge for the player even in the early stages of building a city. E.g. a city with a population of 500 requires fire and police stations as well as an elementary school. When creating the model of Olomouc, a city with a population over 100 thousand, the exaggerated demand for services became unmanageable. The city required tremendous amounts of electricity, water, garbage collectors, firefighters, etc. The unwanted behaviour was mitigated or completely supressed by installing mods such as No Fires, No Need for Pipes, Pollution Remover or custom assets such as Large water station or solar panels producing large amount of electricity. Though the installed mods helped to resolve these issues (again underlining the importance of the modding environment), the best option to manage the simulation accuracy would be a tool provided directly in the game. Such a tool would remove the need for installing numerous mods and greatly improve the game's use for conducting simulation scenarios.

Despite the limitations mentioned above, the game Cities: Skylines include many desirable features and is more than suitable for conducting a study involving city-building games. However, a strong knowledge of the game and the modding environment is required for conducting research involving this game. Due to its limits, the game is optimal for modelling cities up to a population of 200 thousand. Beyond this point the model could reach the limits for created game objects or simply not fit in the available game area. For bigger cities, modelling only a part of the city is recommended.

10.2 Gamified approach to geo-participation

As part of Objective 4, the model of Olomouc was utilized for a design contest for a new neighbourhood, VOP Velkomoravská. The objective of this event was to gather creative ideas for utilizing one of the most valuable brownfields in the city of Olomouc as well as to set a methodology for running a design contest involving a city-building game. The design contest was organized in five stages: preparing the design rules; starting the design contest; collecting designs and creating the presentation material; assessing the designs and finally gathering feedback from the players and the jury.

At the beginning, it was uncertain how many players would participate in the design contest. To gain participants, the contest had to present a compelling challenge to the players and be well propagated. The event was initially advertised on a Reddit forum dedicated to Cities: Skylines and on social media. Then a reminder of the event was posted on Reddit every day. Furthermore, some of the players started to share the link to the original post which greatly helped with the propagation. The level of interest in the contest can be gauged by the number of subscriptions (38) to the starting model of Olomouc, which was published on the platform Steam (Pinos, 2020c). In the end, ten designs were submitted, which provided plenty of material for running a contest. Overall, the interest for the VOP Velkomoravská design contest was higher than expected, especially given the fact that this event was not organized by an institution (e.g. the city) and thus could not offer interesting prizes or other perks to the contestants.

After the contest, feedback was gathered from the players as well as from the members of the jury. The players were asked about the design contest. According to their responses, there were no technical obstacles in installing the starting model, downloading the support materials, or submitting the final design. The biggest obstacle was presented by the design rules, which the respondents considered rather strict (out of 7 responses, 3 considered the rules strict, 3 as neutral and 1 as not strict). This is in contrast to the responses from the jury regarding design rules. Half of the judges considered the design rules to be insufficient (out of 4 responses, 2 considered the rules as not sufficient and, 2 as sufficient). Moreover, the city representative pointed out that an important condition of the city's masterplan - downgrading the high speed road Velkomoravská to a calmer urban road with connections to the neighbourhood – was missing among the design rules, which affected some of the designs that treated the Velkomoravská road as a barrier. This error happened during the preparation of the design rules. In an attempt to simplify the rules by selecting the most important conditions from the masterplan, the development plans for the street Velkomoravská were omitted. The feedback regarding the design rules from both the players and the judges suggest that the preparation of the rules is the most important part of the whole design contest. The design rules must find the optimal balance between playful – so it is compelling to players – and professional – so it can be accepted by experts in the field of spatial planning. The rules should follow the conditions for the modelled area stated in the city's masterplan, but a simplification of these conditions is recommended to attract players. The simplification can reword the original conditions, assign priorities to the conditions, or completely exclude some conditions if they are not decisive for the design outcomes. However, the simplifications should be discussed with the city representatives or, ideally, prepared by city representatives themselves. The city representatives have a deep understanding of the city's masterplan and thus can decide which conditions to include or exclude from the design rules.

A video presentation was created for all the collected designs. This helped to increase the comparability among designs as well as to avoid possible technical difficulties when starting the models in the game. The videos were structured similarly (depending on the amount of information provided), presenting in succession the following aspects of the designs: road network and transport, housing, leisure, shops and services, connection to adjacent areas and within the neighbourhood, and flood protection measures. Despite the video presentations, the jury still found it difficult to compare the designs. According to comments from the judges, the rules should include more criteria such as budget or expected population in order to better compare the designs. Both criteria can be measured in Cities: Skylines, so adding them to any future design contest is recommended. Another option for improving the comparability could be a unified form for presenting the results (same structure, aerial snapshots taken from the same angles, etc.). An ideal but more distant option for improving the comparability would be a tool that allows a simplified version of the model to be viewed (e.g. a static extract). At the moment there is no such tool available, but with the increasing interest in organizing design contests in Cities: Skylines it might be a matter of time before it is created by the game developers or the modding community.

Feedback was also gathered regarding the general use of Cities: Skylines in spatial planning. One player cannot see the game being used as a professional tool for spatial planning but believes the game can be used for observing traffic patterns and visualizing designs. The judges see the game's biggest potential as a tool for brainstorming ideas and critical thinking, while the other uses are seen as conceivable but with some limitations.

The VOP Velkomoravská design contest presented a novel means of geo-participation where players of a city-building game were asked to design a new neighbourhood in a commercial game. Submitted designs from players who accepted the challenge demonstrated a wide range of innovative ideas and different approaches to spatial planning. According to the players' feedback, most of them do not have expertise in spatial planning or similar fields such as GIS. Despite this fact, they were able to use the game model to plan and develop a whole new neighbourhood with all its relations. On the other hand, most of the players involved had considerable experience with the game. In other words, good knowledge of the game is required to participate in a design contest using a city-building game. In this regard, a city-building game does not help to involve the general public – inexperienced both in spatial planning and the game – in decision making, as is the case with studies using simple block builders such as Minecraft (UN Habitat, 2015). This disadvantage of city-building games can be mitigated by involving experienced players in a geo-participation project. Working together with other stakeholders, the experienced players could provide guidance for creating designs in the game.

The description and the results of the VOP Velkomoravská design contest were published in a local magazine and the web portal of the city of Olomouc (*Možnou Budoucí Podobu Nové Olomoucké Čtvrti Navrhovali Hráči z Celého Světa*, 2021; *Studenti ve Hře Řešili Návrh Nové Čtvrti Na Velkomoravské*, 2021).

10.3 Using a game as a simulation tool

The game Cities: Skylines offers numerous simulations and thus could be considered for use as a simulation tool as well. City-building games, including Cities: Skylines, demonstrate many simplifications of the simulation processes, which are often criticized (Bereitschaft, 2016). On the other hand, the modding environment in modern games helps to mitigate or completely overcome these limitations. This is also the case of traffic simulations in Cities: Skylines. Although traffic simulation in this game is arguably the best in the city-building game genre, the simulations still incorporate many simplifications in order to lower the computational load or prevent extensive complexity (Lehto et al., 2015). Numerous mods have been created to modify the traffic simulations in the game, most notably Traffic Manager President Edition (TMPE). This mod offers numerous tools for managing traffic as well as enhancing the simulation logic.

As part of Objective 4, the traffic density was monitored in the model of Olomouc. The model of Olomouc was configured to represent the road system as accurately as possible (appropriate population, zoning, types of roads and junctions, road rules, etc.). Next, the traffic density was monitored in the whole model. To draw a comparison, authentic traffic data were monitored as well (using the HERE Traffic API). The comparison pointed out similarities but also differences in the traffic patterns. Whereas both systems identified similar parts of the road network as problematic, the overall traffic density in the game was higher. This is caused by the game's exaggerated demand for services, which generates a large number of freight vehicles. Therefore, the busiest roads according to the game simulations are near the industrial zones. To mitigate this behaviour, the industrial zones can be made smaller. The optimal solution would be setting the level of demand of the services requesting industrial goods by using an inbuilt tool or a mod.

The traffic density was also monitored for specific scenarios inspired by past or future developments. The first scenario involved demolishing a busy bridge on a route from the city centre to the outer parts of the city. The second scenario involved creating a highway bypass connecting three arterial roads to prevent transit traffic going through the city. In both cases, the simulation presented the expected results. The second scenario confirmed the benefit of constructing the highway bypass by diverting the transit traffic from the city neighbourhoods Holice, Hodolany, Bělidla and Pavlovičky.

The changes in the model's traffic patterns during the day were tested as well. The mod Real Time mimics the day-night cycle and introduces traffic patterns depended on the time of the day (i.e. rush hours). Analysing the monitored data confirmed that there are changes in the overall traffic density during the day, but the changes were much lower than anticipated (i.e. the overall traffic density ranged from 78% - 82%). The description of the Real Time mod offers a possible explanation of the rush hour's low effect on the overall traffic density: the mod works best for cities under the population of 65 thousand. For a model of a city with population 110 thousand, the simulation of the Real Time mod was not as efficient as expected, and thus the changes of the traffic patterns during the day were not analysed. Nevertheless, the use of the Real Time mod is recommended for implementing the realistic day-night cycle. Additionally, this mod could prove great benefit when simulating traffic in smaller cities.

In order to conduct a traffic simulation study in Cities: Skylines, first the real-world area must be modelled in the game. The difficulty of this task is dependent on the solver's knowledge of the game and its modding environment. However, when the model is complete then modifying it using the inbuilt tools, e.g. for simulating scenarios, is straightforward. The TMPE mod offers several options for enhancing the game's traffic simulation logic including an improved path finding cost calculation scheme, enforced parking, and a lane selection algorithm which allows lane changes while in transit. The model of Olomouc used a moderate setting of these options (to use the strictest setting, a model must represent reality at almost a 1:1 ratio). On the other hand, it can be argued that the inaccuracies in the traffic simulations are balanced by the lack of car accidents and reckless behaviour of the vehicular agents.

Despite the inaccuracies found in the traffic simulation, the game Cities: Skylines can be employed as an experimental simulation tool in educational settings, by enthusiasts or even by city planners. The game allows the road network to be modified quickly and for the change in traffic patterns to be observed almost immediately. Moreover, due to the possibility to modify the code of the simulations – either by updating the source code of the TMPE mod or writing a new separate mod –professional use of the game for traffic simulations can be achieved as well.

11. CONCLUSION

The processes of spatial planning are often very complex and involve many stakeholders. Games were first utilized in spatial planning as an education tool but in more recent years have also found uses as tools for simulation, visualization, and engagement of the general public. Therefore, this dissertation thesis explores the possibilities of applying a city-building game in spatial planning.

In Objective 1, the game Cities: Skylines was selected as the game with the highest potential for its use in spatial planning. This game offers a 3D environment enabling the modelling of a real-world place, a wide range of simulations of city-related processes, and most importantly, an extensive modding environment that allows game users to modify the game's looks and behaviour. Additionally, this game has previously been used in spatial planning.

In Objective 2, a new game mod named GeoSkylines was developed in the game's API. This mod consists of approximately 4000 lines of code written in the programming language C#. This mod offers 15 callable methods (9 import, 4 export and 2 helper methods) that create game roads, railways, trees, water basins, services and zoning based on the source geographical data, or export game roads, railways, buildings, trees and zones as geographical data. The mod uses a simple CSV format to store the geographical data with its geometry written in a WKT format. WGS 84 was used as a default coordinate system to store the geographical data. The game's custom coordinate system could be considered as a variation of UTM. Therefore, the conversion of geographical coordinates to game coordinates and vice versa is based on a standard conversion algorithm between the coordinate systems WGS 84 and UTM. The mod GeoSkylines was published on the platform Steam where players can subscribe to it (this action will install the mod into the game and manage further updates). The mod is currently subscribed to by 291 users who use it for recreating a real-world place of their choosing.

In Objective 3, a model of the city of Olomouc was created from geographical data in the game Cities: Skylines. First, datasets for road network, water resources, tree coverage, zoning and services were prepared. OSM was used as a main data source, supplemented by various local data sources. Next, the prepared geographical datasets were imported into the game using the GeoSkylines mod. In this way a base model of Olomouc was created. Last, the model was updated manually (post-processing). This step involved fixing data related issues but also mitigating or completely supressing unwanted behaviour of the game model in order to achieve the set goals of the research. As a result, a playable model of the Olomouc area was created. This area includes the city of Olomouc as well as 25 surrounding small towns (the modelled area covers the majority of the Olomouc municipality).

In Objective 4, the model of Olomouc was utilized in two case studies. The first case study was a geo-participation project in which players were asked to design a new neighbourhood in the model of Olomouc. The selected area is a former military compound, referred to in the city's masterplan as VOP Velkomoravská. This case study happened in five stages: preparing the design rules, starting the design contest, collecting designs and creating the presentation material, assessing the designs, and finally, gathering feedback from the players and the jury. The submitted designs (11 in total) demonstrated a wide range of innovative ideas and different approaches to spatial planning. In the second study case, the model of Olomouc was used for simulating traffic density. First, the traffic density was monitored in the whole model. The results of this monitoring were then compared to authentic traffic data using the HERE Traffic API. Both the simulated data and the authentic data identified similar problematic sections of the road network in the city of Olomouc. Additionally, the traffic density was monitored for two scenarios: demolishing a bridge and constructing a highway bypass. In both cases, the simulation presented expected results. The second scenario confirmed the benefit of constructing the highway bypass by diverting the transit traffic.

The dissertation thesis aimed to answer the following research questions:

1. Can a creation of a game model be automated from geographical data source?
2. Can a city-building game be used as a tool for designing proposed development activities?
3. Can a city-building game be used as a visualization tool for presenting proposed development activities to the public?
4. Can a city-building game be used for the simulation of city-related processes?

In Objective 2, methods and tools were developed to generate the game model from geographical data. During this development, the API of Cities: Skylines was extensively explored. The possibilities of the API in regards to the processing of game objects seem limitless. The problem is in the lack of documentation on how to use the API to generate the game objects correctly. Necessary information was obtained from the source code of other Cities: Skylines mods or by trial and error. As a result, the game mod GeoSkylines can successfully import several types of data but the generated base model still requires manual post-processing to fix the data related issues. There is still space for improvement for the model generation in areas such as incorporating road elevation, merging parallel roads, adding water resources to generated basins or importing buildings. To answer research question 1, a creation of a game model can be automated from geographical data, but with required post-processing of the model.

To use a city-building game for design (e.g. geo-participation) or visualization, the game must provide a sufficient graphics environment allowing a realistic representation of real-world places as well as tools for managing geographical data to ensure accuracy of the created model. The selected game, Cities: Skylines, satisfies both of these conditions. A model of a real-world place can be created in the game by importing geographical data or manually with the help of overlay images of topographic layers. The created model can be shared and used for a geo-participation project or for visualization purposes as presented in Objective 4. This answers the research questions 2 and 3: a city building game can be used for design or visualization if the above conditions are met.

The use of a city-building game as a simulation tool is dependent on several conditions. First, the game must offer simulations of city-related processes as well as an option to adjust these simulations by either using an inbuilt tool or via the game's API. Next, the selected simulation must present realistic outcomes. The quality of the simulation logic can be checked by exploring the algorithms or by testing the simulation against authentic data. The selected game Cities: Skylines offers a wide range of simulations which can be adjusted; in many cases with the use of existing game mods. Additionally, the simulation logic can be further altered by developing a mod using the extensive API. To answer research question 4, a city building game can be used as a simulation tool if the above conditions are met. However, the quality of the simulation is heavily dependent on the game's capability to configure the simulation logic.

The main contribution of this thesis is the overall process of applying a city-building game for spatial planning: from selecting a suitable game, to developing game modifications, to recreating a real-world place in the game, to utilizing the model in two case studies. The developed methods and tools for processing data can be utilized to create game models of real-world places for visualization purposes. The proposed methodology of the case studies can be applied to future geo-participation or simulation projects. This work helped to bridge the gap between the world of playful participation and the world of expertise.

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SHRNUTÍ

Procesy územního plánování jsou často velmi složité a zahrnují mnoho zúčastněných stran. Hry se začaly využívat v územním plánování jako vzdělávací nástroj, ale v poslední době také jako nástroj pro simulaci, vizualizaci a zapojení široké veřejnosti. Tato disertační práce proto zkoumá možnosti uplatnění hry budování města v územním plánování.

V rámci DC1 byla vybrána hra Cities: Skylines jako hra s nejvyšším potenciálem pro její využití v územním plánování. Tato hra nabízí 3D prostředí umožňující modelování skutečného místa, širokou škálu simulací procesů souvisejících s městem a co je nejdůležitější, rozsáhlé modifikační prostředí, které umožňuje upravit vzhled a chování hry. Tato hra byla navíc dříve používána v územním plánování.

V rámci DC2 byl v herním API vyvinut nový herní mod s názvem GeoSkylines. Tento mod se skládá z přibližně 4000 řádků kódu napsaných v programovacím jazyce C #. Tento mod nabízí 15 volatelných metod (9 pro import, 4 pro export a 2 pomocné metody), které vytvářejí herní silnice, železnice, stromy, vodní nádrže, služby a zónování na základě zdrojových geografických dat nebo exportují herní silnice, železnice, budovy, stromy a zóny jako geografická data. Mod používá jednoduchý formát CSV k ukládání geografických dat s jejich geometrií napsaných ve formátu WKT. WGS 84 byl použit jako výchozí souřadnicový systém pro ukládání geografických dat. Vlastní souřadnicový systém hry lze považovat za variaci UTM. Proto je převod zeměpisných souřadnic na souřadnice hry a naopak založen na standardním algoritmu převodu mezi souřadnicovými systémy WGS 84 a UTM. Mod GeoSkylines byl publikován na platformě Steam, kde si hráči mohou přihlásit jeho odběr (tímto se nainstaluje mod do hry). V současné době se k odběru modu přihlásilo 285 uživatelů, kteří jej používají k vytvoření reálných míst podle svého výběru.

V rámci DC3 byl z geografických dat vytvořen model města Olomouce ve hře Cities: Skylines. Nejprve byly připraveny datové soubory pro silniční síť, vodní zdroje, pokrytí stromů, územní plánování a služby. Jako hlavní zdroj dat byl použit OSM doplněný o různé místní zdroje dat. Dále byly připravené geografické datové sady importovány do hry pomocí modu GeoSkylines. Tímto způsobem byl vytvořen základní model Olomouce. Nakonec byl model aktualizován ručně (post-processing). Tento krok zahrnoval řešení problémů souvisejících s daty, ale také zmírnění nebo úplné potlačení nežádoucího chování herního modelu za účelem dosažení stanovených cílů výzkumu. Díky tomu byl vytvořen hratelný model olomoucké oblasti. Tato oblast zahrnuje město Olomouc i 25 okolních malých měst (modelovaná oblast pokrývá většinu hranice města Olomouce).

V rámci DC4 byl model Olomouce použit ve dvou případových studiích. První případovou studií byl projekt geo-participace, kde byli hráči požádáni, aby navrhli novou čtvrť v modelu Olomouce. Vybraným územím je bývalý vojenský prostor, který se v územním plánu města označuje jako VOP Velkomoravská. Tato případová studie proběhla v pěti fázích: příprava pravidel návrhu; zahájení soutěže; sbírání návrhů a tvorba prezentačního materiálu; posouzení návrhů a nakonec získání zpětné vazby od hráčů a poroty. Předložené návrhy (11) demonstrovaly širokou škálu inovativních nápadů a odlišných přístupů k územnímu plánování. Ve druhém studijním případě byl pro simulaci hustoty provozu použit model Olomouce. Nejprve byla v celém modelu monitorována hustota provozu. Výsledky tohoto monitorování byly poté porovnány s autentickými daty o provozu (pomocí HERE Traffic API). Obě monitorování identifikovaly podobné problematické části silniční sítě ve městě Olomouc. Doplňujícím výzkumem bylo monitorování hustoty provozu u dvou scénářů: demolice mostu a vybudování dálničního obchvatu. V obou případech simulace představila očekávané výsledky. Druhý scénář potvrdil výhodu výstavby dálničního obchvatu který napomohl odklonit tranzitní dopravu.

LIST OF APPENDICES

All appendices are included in an electronic form on the flash drive attached to the doctoral thesis.

Appendix 1 – GeoSkylines code and documentation

Appendix 2 – Created models (model of Olomouc used for the research, model of Olomouc by Silvaret, base model of Svit)

Appendix 3 – VOP Velkomoravská (design rules, presentation material of the submitted designs, questionnaires)

Appendix 4 – Traffic simulation (monitoring outputs)

Appendix 5 – SegmentMonitor code

Appendix 6 – Python script for requesting data from HERE Traffic API

VYUŽITÍ BUDOVATELSKÝCH HER PRO ÚČELY PROSTOROVÉHO PLÁNOVÁNÍ

AUTOREFERÁT DISERTAČNÍ PRÁCE

Studijní program: P1301 Geografie
Obor studia: 1302V011 Geoinformatika a kartografie
Školitel: doc. RNDr. Jaroslav BURIAN, Ph.D.

Ing. Jan PIŇOS

THE APPLICATION OF CITY-BUILDING GAMES IN SPATIAL PLANNING

Ph.D. THESIS SUMMARY

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Disertační práce byla vypracována v distanční formě doktorského studia na Katedře geoinformatiky Přírodovědecké fakulty Univerzity Palackého v Olomouci.

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Obhajoba disertační práce se koná před komisí pro obhajoby disertačních prací doktorského studia v oboru P1301 Geografie, studijním oboru 1302V011 Geoinformatika a kartografie, v prostorách Katedry geoinformatiky Přírodovědecké fakulty Univerzity Palackého v Olomouci, 17. listopadu 50, 771 46 Olomouc.

The defence of the dissertation thesis will be held at the commission for the defence of dissertation thesis of Ph.D. degree in study programme P1301 Geography, specialization Geoinformatics and cartography, in the premises of the Department of Geoinformatics, Faculty of Science, Palacký University Olomouc, 17. listopadu 50, 771 46 Olomouc.

S disertační prací je možno se seznámit na studijním oddělení Přírodovědecké fakulty Univerzity Palackého v Olomouci, 17. listopadu 12, 771 46 Olomouc.

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Contents

1. Introduction

Spatial planning is an interdisciplinary field which affects a wide range of human activities and is an essential part of managing and organizing today's developed urban areas. The processes of spatial planning are often very complex and involve many stakeholders such as municipality and town or district representatives, property owners and investors. Therefore, spatial planners use numerous tools which help them facilitate communication among stakeholders, propagate information, model scenarios, engage local citizens, etc. One of the types of tools that have been used in this regard are games.

Games are an integral part of our culture, mostly due to their entertaining qualities. Nevertheless, games can also be used for non-entertainment purposes. Since the second half of the 20th century, games have begun to be utilised in the field of spatial planning to simulate urban-related processes, but also as an experimental education tool or for facilitating participation and communication among stakeholders. Different types of these games include board or card games; pervasive games, which are often played outside in the urban environment; and finally, digital computer games. Whereas non-digital games have remained basically the same, digital games have evolved drastically due to the rapid development of information technologies.

City-building games represent a specific genre of digital games where the player engages in various activities of spatial planning by building and managing a virtual city. Today's city-building games provide visually appealing 3D environments, agent-based simulations of city-related processes as well as the possibility of modifying the game's behaviour. Due to these features, city-building games have begun to be used in non-entertainment ways, e.g. as an educational tool, for simulating various scenarios or for engaging the citizens. Therefore, this dissertation thesis investigates the potential of modern city-building games for practical use in the field of spatial planning.

2. Objectives

The main objective of this dissertation thesis is to create a real-world model in a city-building game from geographical data and then investigate and test the possibilities of the application of such model for the purposes of spatial planning.

At the beginning of this work, city-building games with the potential to be used for the purposes of spatial planning will be selected. Primarily, this work will focus on uses in urban modelling, visualisation, or for facilitating civic engagement. As part of this objective, a set of criteria will be defined for the selection of the game with the highest potential for its application in spatial planning.

Importantly, to use a city-building game for the purposes mentioned above, the game environment must provide a realistic representation of a real-world place or offer options for creating one. This is usually completed using methods or tools for processing geodata (e.g. importing geodata into the game). Therefore, in the practical part of this work, new tools for geodata processing will be developed for the selected game. Using the newly developed tools, geographically accurate models of selected cities will be created. Next, this work will explore possible advantages and disadvantages of the created models in selected case studies, which might include using the model for simulations of urban-related processes or using the model for the geo-design of a selected area (participation project).

Objective 1 – Selection of a city-building game with the highest potential for its application in spatial planning

There are numerous city-building games to choose from. However, not all games can be efficiently used for the purposes of spatial planning. Objective 1 is to select a city-building game with the highest potential for its application in spatial planning.

Objective 2 – Development of geodata processing methods and tools for game world creation

The main focus of this research is given to city-building games with representations of space. City-building games usually operate in imaginary spaces that do not reflect the real world. Though many players have manually created models of various places on Earth in city-building games, the accuracy is often insufficient and the creation process time consuming. If city-building games were to be used for visualisation, participation or simulation projects, the creation of the game world representing a real-world space must be accurate, fast, simple, and repeatable. Objective 2 is to develop set of methods and tools which process geographical data for the selected game. The developed tools will create game objects such as roads, trees, zoning, etc. from the source geographical data, making the overall model creation process more accurate, simpler, and faster. Additionally, the developed tools will also allow for exporting the game objects into a GIS format which can be processed further (e.g. for a data collection participation project). As part of this objective, list of geographic data that can be imported into the selected game will be provided.

Objective 3 – Creation of models in a selected city-building game

In order to use a city-building game for the purposes of spatial planning, a model representing a real-world place must be created (apart from education, where the use of models of imaginary cities is sufficient). The created model must be completed with the highest achievable accuracy. Objective 3 is to create a model (or models) of an urban area of the study interest in the selected city-building game. First, a suitable urban area will be selected. Next, geographical data will be collected and pre-processed for this area. Using the geodata processing tools developed as part of Objective 2, a base model will be created, consisting of game objects such as roads, buildings, zoning, trees, etc. Generated base models might include errors, e.g. due to incorrect geographical data. These errors will be fixed as part of post-processing of the base model. Moreover, the generated model will be calibrated in accordance with the game's requirements. The resulting model will provide a standard gaming experience.

Objective 4 –Utilisation of playable models for spatial planning

The created model (or models) in Objective 3 will represent a selected urban area and as such can be utilised for purposes of spatial planning. Objective 4 is to conduct case studies that will employ the created playable models for purposes of spatial planning. All of the use cases will be documented. In case studies involving participants, a feedback (such as qualitative questionnaire) will be collected, and the responses discussed.

3. State of art

The history of spatial planning is related to the foundation of cities and their development. Various forms of spatial planning can be observed throughout history, from building pyramids in ancient Egypt, to constructing fortified cities in the middle ages, to the continuous development of megacities in the modern era. Today, spatial planning is an essential part of organising and managing public administration. Spatial planning involves many stakeholders: representatives of the municipality and the general public, property owners and investors. In the negotiation process, the involved parties have to come to an agreement that is acceptable to all and also balance three aspects: economic, environmental and social. Another challenge is the growing complexity of today's urban areas as an increasing number of people migrate from rural areas to cities ("World Urban. Prospect. 2018 Revis.," 2019). Because of these challenges, spatial planning requires more information, methods and tools. Fortunately, with the advance of information technologies, numerous tools have been developed to help spatial planners with their work, such as databases for archiving large amounts of information, GIS and CAD software for capturing spatial information, or a wide range of modelling tools for simulating different scenarios to support decision making.

Modelling is a basic concept used for understanding a studied system. Simulation modelling, as one of the types of modelling, provides an option for testing a wide range of scenarios in the studied system. The knowledge gained from running the testing scenarios can then be used to predict the system's behaviour in the future. The three main methods of simulation modelling include: system dynamics, discrete event modelling and agent-based modelling (Grigoryev, 2015). Simulation modelling is widely used in spatial planning for tasks such as simulating land use, transportation, traffic or environmental planning. Popular software applications with a focus on simulation in spatial planning include: What If? (http://whatifinc.biz/), MATSim (https://www.matsim.org/), PTV Visum (https://www.ptvgroup.com/) or UrbanSIM (https://urbansim.com/). These programs are a great asset for professional city planners but are often too complex for a wider audience. For example, in situations such as presenting city plans to the public, coordinating communication among stakeholders, or teaching principles of spatial planning to students, it is preferable to use a less complicated, more attractive tool. Therefore, numerous urban planners have started employing games as the optimal tool for the cases mentioned above.

The concept of utilising games was brought to the field of spatial planning in the second half of the 20th century. Richard Duke, one of the pioneers of simulation gaming in spatial planning, developed a game, Metropolis, which simulated communal budgeting for supporting consensus-building among stakeholders (Duke, 1964). Another earlier urban-related game, The Cornell Land Use Game (CLUG) was a non-digital board game that was designed to support planning processes (Feldt, 1972). Digital urban games developed in the 1960's and 1970's utilised large-scale models for their simulations. These simulations however, turned out to be largely inaccurate and failed to provide conclusive outcomes (Lee, 1973). Despite feeling disillusionment about the simulation capabilities of large-scale models, many scholars looked for other uses of games in the field of spatial planning, such as facilitating participation and communication among stakeholders (Armstrong & Hobson, 1972).

An important reason for the continuous effort toward employing games in the field of spatial planning is also their immense attractivity, especially in the case of modern digital games. According to a recent survey conducted by the Pew Research Center, 90 percent of surveyed teenagers play video games of some kind either on a cell phone, computer or a console (Anderson & Jiang, 2018). However, games are attractive to almost everyone and not just teenagers. A market study from 2010 reports that the serious games market is worth 1.5 billion € (Alvarez et al., 2010). As for commercial games, the profits are growing every year, in 2018 reaching $2.4 billion (Market Brief - 2018 Digital Games & Interactive Entertainment Industry Year In Review, 2018).

Serious games and commercial video games

Games that were developed by scholars or spatial planners to solve a specific scenario, some of which were mentioned above, have begun to be labelled as "serious games". Clark C. Abt (1970) introduced the term "serious games" in his influential book of the same name, "Serious games". Abt defines this term as games that "have an explicit and carefully though-out educational purpose and are not intended to be played primarily for amusement". Since then the term has evolved, incorporating any non-entertainment uses of a game such as simulation, propagation, visualisation or participation, and thus the term serious games could be simply rephrased to: games with a non-entertainment main goal. Djaouti, Alvarez, Jessel, & Rampnoux (2011) provide a comprehensive analysis of the former and current use of serious games. The term "serious games" helps to distinguish these types of games from commercial video games that are developed to be mainly entertaining and thus appealing for the player or potential buyer. For a long time, serious games and commercial video games served different purposes. However, this started to change at the end of 20th century when a few commercial games started to be used "seriously", i.e. with a main purpose other than entertainment. The prime example is the city-building game SimCity, which, contrary to the majority of commercial games of that time period, took on the risk of implementing open-ended simulations of city planning processes. This game found its community and turned out to be commercially successful, proving that more realistic approach does not have to be limited only to "serious games".

City-building game genre overview

Most city-building games can be described as a single player open-ended game, where the player as an all-powerful mayor plans, builds and manages a virtual city. The objective of the game is not to reach specific goal but rather build a prosperous city with satisfied inhabitants. While playing a city-building game, the player learns about city related processes and their dependency.

While limited in its simulation, The Summer Game, coded in 1968 by Doug Dyment, is considered to be the first computer game concerning city building and management (Moss, 2015). Several experimental titles followed but the big success came later with the release of SimCity in 1989 from the development studio Maxis. Will Wright, the lead developer and co-founder of Maxis, implemented various aspects of urban planning and computer modelling into SimCity, creating a complete city-building game that set the standard for the following titles.

After the commercial success of the original SimCity, new city-building games followed (within the SimCity series as well as titles from other development studios): SimCity 3000, SimCity 4, Tropico, CityLife etc. SimCity 2013 - the most recent title in the SimCity series - encountered several problems after its release, which led to the game's poor reception among players. In 2015, the Finnish game development studio Colossal Order released their take on a city-building game, named Cities: Skylines. This game was well received as it delivered desired features such as a 3D graphics environment, an extensive API for creating game modifications, a mass transit system, and well-functioning agent-based simulations controlling citizens, vehicles, and other game objects (Moss, 2015). Today, Cities: Skylines is arguably the best city-building game on the market. This can be concluded from (1) its commercial success, where Cities: Skylines has sold over six million copies (Cities: Skylines Celebrates Fourth Anniversary and Six Million Copies Sold, 2019) compared to SimCity 2013's two million copies (Matulef, 2013); and (2) the size of the gaming community gathered on forums on Reddit.com; where the forum dedicated to Cities: Skyline has more than 300,000 subscribers (R/CitiesSkylines, 2019), whereas the forum dedicated to SimCity is followed by the much lower number of 25,000 subscribers (R/SimCity, 2019).

In Cities: Skylines, the player engages in urban planning by establishing the road network, controlling zoning, providing public services and public transportation, and taxation. The player maintains various elements of the virtual city such as its budget, education, employment, pollution levels, etc. The simulated phenomena can be monitored in the game's "info views" that provide visually attractive outputs (Info Views, 2019).

City-building games enabling participation in spatial planning

The majority of the world population now resides in urban areas and this trend will continue to grow due to an estimated 3 million of people migrating every day from rural areas to cities ("World Urban. Prospect. 2018 Revis.," 2019). At the same time, inhabitants of urban areas want to be more involved in the spatial planning processes which are, however, often too complex to comprehend. Therefore, there is a need to bridge the gap of data, information and knowledge between the public and planning processes. One of the ways how to achieve this is by using games that provide a means of playful participation in an attractive environment.

Numerous serious games have been used for participation projects, proving that the game approach is beneficial (Gordon et al., 2011; Gordon & Baldwin-Philippi, 2014; Poplin, 2014). Recently, commercial video games have started to be utilised for civic engagement as well. The technical and financial possibilities of the studios developing commercial video games are great (especially compared to serious games). Moreover, video game titles utilise gaming engines such as Unreal or Unity 3D that are at the forefront of progress in the visual graphics field. Therefore, commercial video games can often attract wider audiences. One of the games utilised for spatial planning is Minecraft. Minecraft has a large and active world-wide online community of over 100 million players. UN-Habitat saw the potential in the game's possibilities and its active community and has partnered with the creators of Minecraft, the development studio Mojang, to start a program called Block by Block. In this program, Minecraft is used to help with redevelopment of selected areas. First, using geographical and satellite data, a model of the selected area is created within Minecraft. This base model is then presented to the surrounding community, whose members use, or rather play, the game to rebuild the modelled area according to their wishes. Finally, the resulting models are translated into plans for further implementation (UN Habitat, 2015). A similar participation project was done in the city of Exeter, England, where Minecraft was utilised for a design challenge of the town's historic centre (Building a Sustainable Future with the Exeter 2025 Minecraft Challenge, 2019). Recently, a case study in Brazil used Minecraft as a tool for engaging children in urban planning (de Andrade et al., 2020).

The game Cities: Skylines is built on the Unity 3D engine and thus offers a visually appealing environment in a spacious 3D world that can be roamed almost freely. In this game, the players usually build and manage imaginary cities. However, since this game allows building a city in great detail, many players started to model their hometowns or other well-known places in the world (Amazingly Detailed Metropolises Recreated in Cities: Skylines – in Pictures., 2015). There have also been several case studies where the game Cities: Skylines was used more professionally. The city of Hämeenlinna in Finland held a contest to design a new suburb near the city centre using the game Cities: Skylines. Players were given a base map of the city, which was prepared by the workers of the council, and then started building roads, buildings and services for the new suburb within the game (Brethonière, 2020; Guzman, 2016). The contest was open to players from all around the world and as such brought more diversity to the design ideas. On the other hand, Silvain Hamar de la Brethonière (2020) points out that international players lack a real connection to the modelled area and thus the participation part is questionable.

Another use of the game Cities: Skylines aimed to involve local citizens. In Stockholm, Sweden the game was used to model the intended development of the Royal Seaport district. The resulting model was then offered to the general public who could then explore the modelled area and contribute new ideas to the development plan (Andrew, 2016; Video Game Cities Skylines Helps Plan Stockholm Development, 2017).

City-building games as urban modelling tools: potential and limitations

City-building games represent a specific game genre due to their simulation of urban-related processes. Simulations in city building games often use similar models as modelling tools used in research: cellular automata, gravitational models, feedback loops (Prensky, 2001; Rufat & Ter Minassian, 2012). Cellular automata are also often used in video games, including Cities: Skylines, to simulate the behaviour of gasses, liquids, temperature, and electricity (vanden Broucke, 2017). The most used modelling tool in city-building games is the agent-based model that controls the behaviour of citizens, vehicles, and other game objects. These agents interact between each other independently of the mayor's (player's) actions, creating an artificial society where real-life phenomena emerge (Devisch et al., 2009). With the use of the agent-based model, the player could build a city that is close to the chaotic, unpredictable and self-organizing system defining modern cities (Portugali, 2000).

Rufat & Ter Minassian (2012) in their study compared selected city-building games with modelling tools used in research. Rufat & Ter Minassian (2012) conclude that simulations in the city-building games are based on similar models to the ones used in research, but the main difference is in the ability to change the simulation parameters after observation and learning. Whereas scholarly modelling tools offer this feature, games do not. In other words, simulation logic in games is a "black box" – most often due to the protection of intellectual property - where the rules can be deduced only through exploration. This problem was also highlighted by Devisch (Devisch, 2008), who studied the possible use of SimCity in planning processes, and D'Artista & Hellweger (2007), who studied SimCity from the point of view of urban hydrology.

City-building games are also criticised for their simplification of urban processes. For example, the lack of mixed zone usage, a concept seen as beneficial among urbanists (Jabareen, 2006), was spotted in early versions of SimCity (Starr, 1994) and later in SimCity 4 and Cities: Skylines (Bereitschaft, 2016). City-building games are played from the position of all-powerful mayor, though in reality, the planning processes involve many stakeholders (Bereitschaft, 2016; Haahtela, 2015). On the other hand, it is important to note that urban planning processes are complex, and as such cannot be conclusively modelled even with scholarly tools (Batty & Paul M. Torrens, 2001). Many simplifications are made due to our current inability to implement the full complexity of urban systems into the game. Nevertheless, some simplifications are incorporated into the games simply to enhance the playability of the game, thus making it more appealing to the player, a potential buyer (Dzieza, 2013; Fulton K., 2015).

Modifying the game through custom scripting

In general, the use of commercial video games in their original version for non-entertainment purposes is quite limited. However, these limitations, including the ones mentioned above, can be overcome or at least mitigated by incorporating changes to the game's behaviour. The process of changing the game using custom scripting is known in the gaming community as "modding" (Scacchi, 2010). This process can modify the original version of a video game to solve a given problem. Modding represents a way of accessing and changing the game's "black box" behaviour.

Most modern video games offer the possibility to change the game's behaviour through modding as this is a desired feature by the gaming community. However, the level of extensiveness and support of modding varies from game to game. Whereas in some cases the modding possibilities are quite limited, in other cases the game's behaviour can be changed significantly.

For example, the city-building game Cities: Skylines provides an extensive application programming interface (API) written in the programming language C# and modding support in form of online documentation and user forums. This feature is highly appreciated by the game's community; this is best documented by the large number of mods in existence: 175,970 created by the beginning of 2019 (Cities: Skylines Celebrates Fourth Anniversary and Six Million Copies Sold, 2019). Most of these mods are cosmetic additions to the game (e.g. a new type of tree) but some mods are professionally written modifications to the game's behaviour: changing the traffic management, allowing mixed zones, providing for the preservation of historic buildings, importing and exporting geographical data into the game, etc.

In a study done by Juraschek, Herrmann, & Thiede (Juraschek et al., 2017), a model of the city Braunschweig, Germany was created using selected mods in the game Cities: Skylines to simulate the production of urban factories and evaluate various phenomena such as air pollution. A recent study implemented the game Cities: Skylines as a tool for simulating natural hazards to a university course for environmentalists (Fernández & Ceacero-Moreno, 2021).

The above studies implemented existing mods to modify the game to achieve the desired behaviour. Following studies went a step further and introduced the desired behaviour by developing a new game mod. Olszewski, Cegiełka, Szczepankowska & Wesołowski (2020) in their study programmed a mod for importing topographic data stored in CityGML format. The created model was then used for developing a serious game within the toolset environment of Cities: Skylines. Eisele, Mardari, Dubey, & Karsai (2017) in their study implemented significant modifications to the game Cities: Skylines in order to simulate decentralized smart traffic systems. The team at the KAUST university lead by Shehab Ahmed (personal communication, July 28, 2020) is using modified version of Cities: Skylines to conduct real-time traffic and energy consumption simulations in modelled cities.

4. Selection of a city-building game with the highest potential for its application in spatial planning

In order to achieve the research goals of this thesis, a suitable game had to be selected first. Given the focus of this work to spatial planning, games that enable a player to build and manage a city were preferred. The best option to consider were commercial video games with the modding capability. These types of games are highly attractive, supported by large development studios and, thanks to the modding capabilities, offer the possibility to modify the game's behaviour to fit the purpose of the study (Pinos, 2019).

Evaluation criteria

The selection of the game was based on several aspects. First, the selected game had to be attractive and relevant to today's players. The attractivity of a game in this regard is not understood as a visual attractivity but rather how the game is perceived by the wider gaming community. It is assumed, that a game, that is attractive to a large number of players, has certain level of quality and does not include any critical issues preventing a sensible use. In this case, the number of copies sold and the number of subscribers of a user forum dedicated to the game were considered as indicators of the game's attractivity. Next, the selected game had to offer a sufficient graphics environment, so that a real-world place can be representatively recreated within the game (e.g. the game should offer 3D environment). Furthermore, the selected game had to provide extensive modding capabilities, which enable modifying the game's looks and behaviour. Beside the programming interface, the game should offer sufficient documentation and support of the modding environment. Last, the selected game had to represent city related processes and optimally be previously used in a spatial planning. The above aspects were represented in following evaluating criteria used for the game selection: Attractivity (in number of copies sold), Attractivity (in number of subscribers of the user forum dedicated to the game), Provides city-related simulations, Previous uses in spatial planning, Provides 3D space representation, Provides a modding environment, Provides modding support, Enables geodata processing.

Evaluated games

Evaluation of all commercial games, with the focus on city-building, that are available on the market was outside of the scope of this research. Therefore, the following games have been pre-selected for evaluation based on the author's own experience: Minecraft, Cities in Motion 2, Cities: Skylines, SimCity 2013.

Evaluation table

Pre-selected games are evaluated against the chosen criteria in the Table 1. The criterion Copies sold represents the total number of copies sold in millions. The criterion Community represents the number of subscribers on the Reddit.com subforums dedicated to the particular game (e.g. reddit.com/r/Minecraft) in thousands. The following criteria are recorded as a Yes/No option. The criterion Urban simulations states whether the game offers out-of-the-box simulations of city-related processes. The criterion Previous uses states whether the game has been used previously for purposes of urban planning. The criterion 3D space states whether the game offers a 3D graphics environment. The criterion Modding environment states whether the game offers tools to modify the game. The criterion Modding support states whether the game offers learning material and support for creating custom game modifications. The criterion Geodata processing states whether the game offers tools for processing geographical data (e.g. data import). Game names were shortened as follows: Cities in Motion 2 (CiM 2), Cities: Skylines (C: S), SimCity 2013 (SimCity).

Table 1 Evaluation table of pre-selected games.

Games	Minecraft	CiM	C: S	SimCity
Copies sold	180	1	6	2
Community	2500	1.2	273	25.9
Urban simulations	No	Yes *	Yes	Yes
Previous uses	Yes	No	Yes	Yes **
3D space	Yes	Yes	Yes	Yes
Modding environment	Yes	Yes	Yes	Yes
Modding support	Yes	No	Yes	No
Geodata processing	Yes ***	No	Yes ***	No

* only traffic and transportation simulations
** only education using imaginary cities
*** combination of inbuilt and 3rd party tools

As the numbers suggest, Minecraft is the most attractive game in the evaluation. It also has been used previously in spatial planning for visualisations. But other uses are quite limited as Minecraft does not offer out-of-the-box city-related simulations.

The potential of SimCity 2013 for its application in spatial planning is heavily limited by an insufficient modding environment. Particularly, the lack of modding documentation and support would make the development of geodata processing tools very difficult.

Cities in Motion 2 scored the worst; however, due to its specialised focus on transport and traffic management, building a model of a real-world place might be worth exploring.

Cities: Skylines achieved the highest score. Though the numbers of players and copies purchased is not as impressive as in the case of Minecraft, it is still the best-selling game in the city-building genre. Cities: Skylines provides a well-supported modding environment, enabling the development of geodata processing tools. This game can be used in all intended purposes of spatial planning. Therefore, the game Cities: Skylines has been selected as the game with highest potential for the application in spatial planning.

5. Development of geodata processing methods and tools for game world creation

The game Cities: Skylines offers extensive API that can be used to modify the original version of the game. Using the API written in programming language C#, a game mod was developed for generating game objects from pre-processed geographical data. This game mod was named GeoSkylines. GeoSkylines is available on the platform Steam (Pinos, 2020b). The source code and full documentation is available on GitHub (Pinos, 2020a).

Geographical data input format and pre-processing

Since the game does not work with common GIS data formats, the easiest way to upload the geodata was to use a CSV file with geometry recorded in a WKT format. WGS84 was selected as a default coordinate system for storing geodata. Geodata were collected from freely available sources, predominantly from OSM. OSM data were downloaded using QGIS and the QuickOSM plugin. Another QGIS plugin, HCMGIS, provides a selection of base maps that help with navigating to the area intended for modelling.

The downloaded OSM data are stored only in memory and thus must be exported as permanent CSV files. Import methods of the GeoSkylines mod require specific fields (columns) to be present in the CSV files such as road_name, road_type etc. for creating the game objects. Renaming fields or deleting unnecessary fields can be done in MS Excel or Notepad. The naming convention for the CSV files for import is "<object_name>_rwo.csv" (e.g. roads_rwo.csv). The naming convention for the exported CSV files is "<object_name>_cs.rwo". The CSV files are loaded from the game's default folder (usually c:\Program Files (x86)\Steam\steamapps\common\Cities_Skylines\Files\). This folder also contains CSV files for matching geodata types with game object types (e.g. types of roads) and a configuration file import_export.txt. The configuration file import_export.txt contains numerous parameters, in the format of parameter_name: parameter_value, which are used by the methods of the GeoSkylines game mod. Parameter MapName serves an orientational purpose for the solver. Most important parameters are CenterLatitude and CenterLongitude which are used for converting geographical coordinates to game coordinates and vice versa.

Conversion of coordinates

The game Cities: Skylines utilises a projected coordinate system using metres as units in a game area of 17.28 km x 17.28 km. This coordinate system has three axes: x, y and z. The axis y, contrary to the geographical standards, stores height values (behaviour inherited from the gaming engine Unity 3D). Axis x serves as 'easting' and axis z serves as 'northing'. The point of origin is in the centre of the game area and the axes x and z range from -8640 to 8640. The game's coordinate system can be considered as a variation of the UTM projected coordinate system. Thus, for the coordinate conversion, I used a standard algorithm for converting WGS 84 coordinates to UTM coordinates and then recalculated the UTM coordinates to the game coordinates.

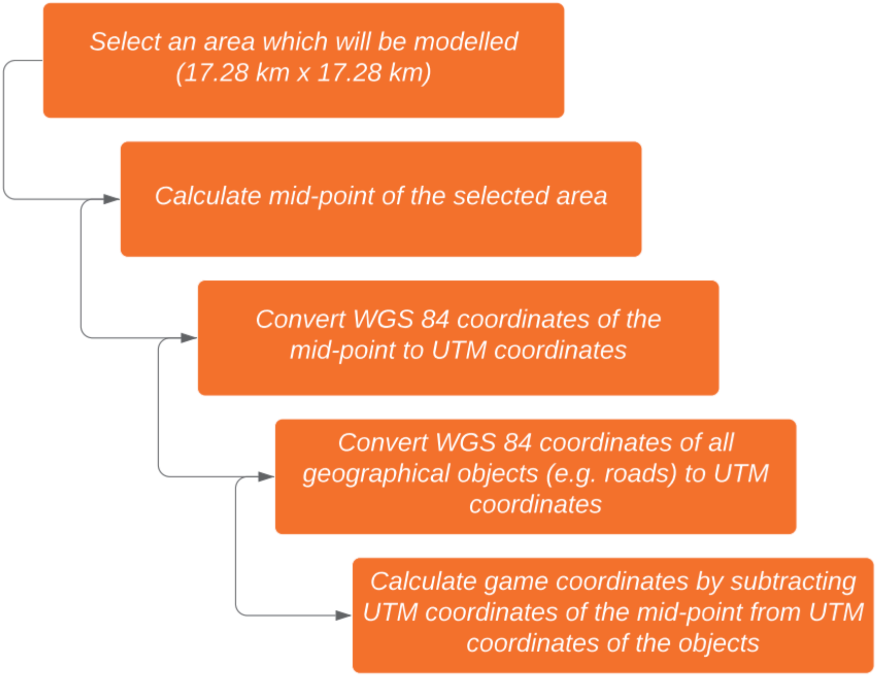

Figure 1 Schema of the conversion of geographical coordinates to game coordinates.

Coordinates of the game object are calculated according to formulas 1 and 2:

$$X = E_O - E_M \qquad (1)$$

$$Z = N_O - N_M \qquad (2)$$

where X and Z represent the game axes in 2D space, E represents easting, N represents northing, O represents the geographical object and M represents the mid-point.

GeoSkylines import methods

Main functionality of the GeoSkylines game mod are its import methods that generate game objects based on the loaded geographical data. Using these methods, road and rail network can be generated as well as water basins and tree coverage. GeoSkylines import methods are activated in the game via hot key combination. Table 2 displays the full list of import methods of the GeoSkylines game mod.

Table 2 List of import methods of the GeoSkylines game mod.

Method name	Method description	Hot key	Requires
ImportRoads()	Uploads roads_rwo.csv, matches road types according to rwo_cs_road_match.csv and creates a road network.	Right Ctrl + R	roads_rwo.csv, rwo_cs_road_match.csv, import_export.txt
ImportRoadNames()	Intended for updating road names of manually constructed roads.	Right Ctrl + M	roads_rwo.csv Import_export.txt
ImportRails()	Uploads rails_rwo.csv, matches rail types according to rwo_cs_rail_match.csv and creates a rail network.	Right Ctrl + L	rails_rwo.csv, rwo_cs_rail_match.csv, import_export.txt
ImportWaterReservoirs()	Uploads water_rwo.csv and lowers the terrain for each polygon using the Ray casting algorithm.	Right Ctrl + W	water_rwo.csv, import_export.txt
ImportWaterWay()	Uploads waterway_rwo.csv and lowers the terrain for each waterway segment.	Right Ctrl + Q	waterway_rwo.csv, import_export.txt
ImportTreesRaster()	Uploads trees.png and for every non-white pixel creates a tree.	Right Ctrl + T	trees.png (1081 x 1081 resolution), import_export.txt
ImportTreesVector()	Uploads trees_rwo.csv and creates a tree for each record.	Right Ctrl + V	trees_rwo.csv, import_export.txt
ImportZones()	Uploads zones_rwo.csv, matches locations of each zone with the locations of game's zone blocks and sets the zone.	Right Ctrl + Z	zones_rwo.csv, rwo_cs_zone_match.csv, import_export.txt
ImportServices()	Uploads amenity_rwo.csv, matches service types according to rwo_cs_service_match.csv and creates services.	Right Ctrl + S	amenity_rwo.csv, rwo_cs_service_match.csv, import_export.txt

GeoSkylines export methods

The newly developed game mod GeoSkylines also provides methods for exporting game objects, specifically trees, roads, railways, buildings, and zoning into a GIS format that could be then further processed. GeoSkylines export methods are activated in the game via hot key combination. Table 3 displays the full list of export methods of the GeoSkylines game mod.

Method name	Method description	Hot Key	Requires
ExportSegments()	Exports all road segments created in the game into a CSV file.	Right Ctrl + G	import_export.txt
ExportBuildings()	Export all buildings created in the game into a CSV file.	Right Ctrl + H	import_export.txt
ExportZones()	Exports all zones created in the game into a CSV file.	Right Ctrl + J	import_export.txt
ExportTrees()	Exports all trees created in the game into a CSV file.	Right Ctrl + K	import_export.txt

6. Creation of models in a selected city-building game

This section describes the process of creating models of cities Svit (Slovakia) and Olomouc (Czech Republic) in the game Cities: Skylines. The creation of a model is in this text distinguished into two stages:

- Generating a base model using GeoSkylines import methods
- Manual post-processing of the base model into a final, playable model

In case of the city of Olomouc, first a base model was generated and then this model was further processed into two playable models of Olomouc that will be described below.

Creation of the Olomouc base model

The city of Olomouc (Czech Republic) is the 6th biggest city in the country, with a population of 100,378 inhabitants (2019). This city is very old, especially the centre, which contains many churches and other historic buildings. This city was selected for this research for its history and size. The mid-point of the modelled area was located to 17.247812, 49.588705 (longitude, latitude). The selected mid-point was then used to calculate a geographical bounding box of 17.28 km x 17.28 km, representing the size of the Cities: Skylines game area. Next, following geographical datasets were obtained for the Olomouc area:

- PNG heightmap generated from DEM DMR5G tile using QGIS and the gdal_translate command:
- Road vector layer from OSM (tag highway). This layer was converted to a file roads_rwo.csv.
- Waterway layer from OSM (tag waterway). This layer was converted to a file waterway_rwo.csv.
- Water body layer from OSM (tag natural=water). This layer was converted to a file water_rwo.csv.
- PNG image of a tree coverage from the Urban Atlas Street Tree layer. This layer was clipped according to the defined area.
- Service vector layer from OSM (tag amenity). This layer was converted to a file amenity_rwo.csv.
- Dataset Funckni_plochy_zastavba_upraveno (derived from a dataset Functional Zones Olomouc) that combines the information about function of a specific area with the information about the type of housing in that area (Pavlis, 2019).

Next, matching files were prepared, where geographical object types were matched to appropriate game object types. For road type matching, file rwo_cs_road_match.csv was used. For matching services, file rwo_cs_service_match.csv was used. For matching zone types, file rwo_cs_zone_match.csv was used.

After preparing all datasets and matching files, the base model of Olomouc in Cities: Skylines was completed following the steps below:

- Generating the terrain in the game's map editor, using the inbuilt option for importing heightmaps in the PNG format.
- Manually adding at least 2 outside connections (highways) and a water source in the starting tile (required by the map editor to save the map as playable). This allows us to generate the rest of the model in the actual game rather than the map editor where the generated results behave differently (e.g. roads are elevated by 1 meter). The added items are temporary and can be modified or deleted later.
- Calling GeoSkyline's method ImportRoads() to generate the road network in the game.
- Calling GeoSkylines' method ImportWaterWays() to generate water basins for waterways in the game.
- Calling GeoSkylines' method ImportWaterReservoirs() to generate water basins for resources of standing water in the game.
- Calling GeoSkylines' method ImportTreesRaster() to generate tree coverage in the game.
- Calling GeoSkylines' method ImportServices() to generate service buildings in the game.

Figure 2 displays the base model of Olomouc generated in the game by calling the import GeoSkylines methods.

Figure 2 A base model of Olomouc in Cities: Skylines generated by calling GeoSkylines methods.

Creation of a playable model of Olomouc

Using GeoSkylines import methods for generating game objects from geographical data reduces the work necessary to create a model of a selected city. Nevertheless, manual post-processing is still required in order to turn the generated base model into a playable model that can be used for visualisation or simulation purposes. The manual post-processing of the Olomouc model consisted of following stages: Adding water resources; Fixing road network; Creating zoning (using the ImportZonesArea() method); Mitigating unrealistic simulation of the game; Creating a public transport system; Adding playgrounds, sport grounds, parks, and unique buildings such as churches and skyscrapers.

Though the generated road network is topologically connected, there are issues that require modifying. As discussed in objective 2, GeoSkylines mod is not adding elevation to the created roads. Therefore, all overpass roads and elevated bridges lay flat on the terrain. This issue can be fixed by elevating the roads with the Move It mod (Move It, 2019) or by recreating them using the in-game road tools. Tram tracks are in Cities: Skylines often part of a road (e.g. Two-lane road with tram tracks). Generating roads with tram tracks from combined roads and railway geographical data would be too complex. Therefore, in the Olomouc model the tram network was manually built using the game's transportation tool (the DLC Snowfall must be installed for constructing a tram network). A tram depo was built in a place where the real Olomouc tram depo is located. The geographical representation of junctions might include separate line geometries for turning lanes. The GeoSkylines mod successfully imports this type of representation, but the resulting junction is slowing down the car agents in the game as they see the connected turning lanes as another junction.

Cities: Skylines is a game that aims to entertain and thus some of the game's simulations are simplified whereas others present an unexpected challenge to the player. For example, the need for fire services is exaggerated in order to create a challenge for the player even at the early stages of the game. However, for larger cities the amount of fire services required is unrealistically high. In reality, there is only one major fire station in Olomouc but adding only one fire station to the game model would result in constant fires. This and other unrealistic or unwanted behaviour of the game was mitigated or completely suppressed by installing mods such as 81 Tiles, Life Cycle Rebalanced, Realistic Population and others. All mods are freely available on the Steam platform.

Model of Olomouc

The final model of Olomouc was created with the help of import methods of the GeoSkylines mod as well as manual modifications. Majority of the buildings in the model were generated by the game engine (contrary to individual placement of each building), hence the more generic look of the model. The aim was to create a model that is easy to use and share. In this regard, the model runs without any issues. The model consist of the city of Olomouc and its neighbourhoods (defined as game's districts) – Olomouc Město, Hejčín, Řepčín, Tabulový Vrch, Neředín, Černovír, Lazce, Nová Ulice, Nové Sady, Povel, Nový Svět, Hodolany, Pavlovičky, Holice, Bělidla, Chválkovice and Týneček – and surrounding villages and small towns – Slavonín, Nemilany, Kožušany, Blatec, Nedvězí, Bystročice, Hněvotín, Ústín, Příkazy, Skrbeň, Břuchotín, Horka nad Moravou, Křelov, Chomutov, Hlušovice, Dolany, Tovéř, Samotišky, Svatý Kopeček, Droždín, Velká Bystřice, Bystrovany, Velký Týnec, Vsisko and Grygov. Population of the whole model is around 110 thousand. The mod CSL Show More Limits provides the information about the number of game objects created (CSL Show More Limits, 2017). The number of created segments (includes roads, pedestrian paths, and railways) is 29,841 out of maximum 36,352. The number of created road nodes is 28,948 out of maximum 32,256. The number of active vehicles is 7,836 out of maximum 16,384. This means that the traffic simulations are not limited by the maximum number of active vehicles.

Figure 3 A playable model of Olomouc in Cities: Skylines (historic centre).

Figure 4 Aerial image of Olomouc (historic centre), data source: http://maps.google.com

Figure 3 shows the city centre of the final model of Olomouc. For comparison, Figure 4 shows the aerial image of the historic centre of the city of Olomouc.

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7. Utilisation of playable models for spatial planning

As part of this objective, the created model of Olomouc in Objective 3 was tested in two case studies in spatial planning. First case study was a participatory geo-design project. For this case study a suitable area intended for development had to be selected. After consideration, the area known in the city's masterplan as VOP Velkomoravská was selected as the best option. In the second case study the focus was given to traffic simulations in the created model of Olomouc. The traffic density in the model of Olomouc will be monitored for the whole road network as well as for specific scenarios that involve modifying the infrastructure.

Olomouc VOP Velkomoravská – designing a new neighbourhood in Cities: Skylines

The city of Olomouc is planning to redevelop a former military compound and the surrounding localities into a mixed residential area. The area in question is referred to in the city's masterplan as VOP Velkomoravská (Územní Plán Olomouc, 2020). This area was selected for a design project in the game Cities: Skylines, where players from the gaming community were asked to create their design of the area. The aim of this case study was to test the ability of Cities: Skylines to create designs that are attractive, comprehensible, and effective for both the public and the experts. VOP Velkomoravská is roughly bounded by the streets Velkomoravská, U rybářských stavů, Přichystalova and Holická. The largest part of VOP Velkomoravská is a former military compound that has been closed to the public for many years. The compound is now abandoned with most of its buildings left in ruins, making the area unattractive. Furthermore, the area's inaccessibility caused a division between surrounding city parts: Nový Svět and Povel, and Nový Svět and the city centre. The goal of the design was set to create a modern and attractive neighbourhood in the VOP Velkomoravská area, that will consist of residential and commercial housing as well as public spaces and local services such as doctors. The new neighbourhood should also fix the current division by sufficiently connecting it with surrounding city areas: Nový Svět, Nové Sady, Povel and the city centre.

All designs had to follow the criteria which are stated below. These criteria are based on the regulatory plan defined for the VOP Velkomoravská area in the city's masterplan. Though, only the most important rules were selected, and the wording was simplified in order to communicate it better to the interested players. The design must be located within the specified boundaries. An image file was prepared to easily display the boundary of VOP Velkomoravská. Most of the housing used in the design should be residential. According to the city's masterplan, around 40% of the VOP Velkomoravská area should be dedicated to residential housing. The design should include enough public spaces (parks, squares, or other meeting places) and greenery. According to the city's masterplan, in the area, there must be one public space at 12/056P as well as one public space at 12/054Z. In both cases the area of the public spaces must be at least 0.3 ha, the side ratio must range from 1:1 to 1:3 (i.e. noodle shaped spaces are not allowed). Aside from the public spaces, around 30% of the VOP Velkomoravská area should be dedicated to greenery. The design should connect VOP Velkomoravská with neighbouring areas. Additionally, the area should be connected to a public transport system. The city's masterplan defines pedestrian paths connecting to neighbouring areas. An image file was prepared to display the planned pedestrian paths in the VOP Velkomoravská area. The design should not include buildings higher than 6 floors. According to the city's masterplan, the max height of buildings in this area should be 17/21 meters (edge of the building / top of the roof). However, this criterion was considered with a tolerance (especially for unique buildings).

Figure 5 VOP Velkomoravská according to design by Silvaret (sports hall at the entrance from Velkomoravská road).

In total 11 designs were collected and assessed by the jury. Following experts accepted the invitation to the jury: academicians Doc. Jaroslav Burian, Ph.D and Doc. Jiří Pánek, Ph.D., city representative Ing. arch. Petra Růžičková and a representative of the real estate company RedStone owning the property VOP Velkomoravská Mgr. Pavla Hluštíková. In the overall rating (combining the parametrical rating with the rating of the jury), the best rated designs were: 1. – 2. Silvaret and Ian Witte (with a total score 43); 3. – 5. Jessie G, Andrew C Webb, and Niko Eriksson (with a total score 38).

Figure 6 VOP Velkomoravská according to design by Silvaret (park in between housing blocks).

Traffic simulations in the modelled city

In this case study the focus was given to selected traffic simulations in the created model of Olomouc. First, the traffic congestion of the road network was simulated in the whole city model. Traffic density was observed in standard playing conditions as well as in simulated morning and afternoon traffic peaks. Beside visual observation, the simulation results will be exported into a text file. The results of the simulated traffic congestion will be compared to data obtained from HERE Traffic API. By comparing the simulation results with authentic traffic data, an evaluation of the game's simulation accuracy was completed. Additionally, using the game's features, the model of Olomouc was modified in order to model various traffic scenarios. These scenarios included demolishing a part of a road network (e.g. a bridge) and building a highway bypass connecting arterial roads D/35, I/55 and I/46.

Using the game's Road Tool, the player can construct roads of various types and shapes. A game road consists of segments and nodes that create a complex interconnected topological network. Inhabitants of the modelled city then utilize the road network to travel to work, school, shops, etc. The game individually tracks the passage of every citizen's vehicle as well as service and freight vehicles. In the traffic info view, the player can observe the traffic flow of each road and identify problematic parts of the road system. Each citizen of the virtual city, controlled by an agent, has possible locations they wish to visit. The game takes into account if the citizen owns a vehicle, the congestions of the roads and whether a public transport is available. According to these factors, the game, using A* pathfinding algorithm, chooses a way of travel for the citizen (How Traffic Works in Cities: Skylines, 2020). There are also simplifications incorporated in the traffic simulation, mostly to prevent heavy computational load and excessive complexity. Some of these simplifications include hard set limits for simulated vehicles, transporting a stuck vehicle to its original destination or sticking to a route that has been originally planned and not recalculating it constantly (Lehto et al., 2015). There are numerous, freely available, Cities: Skylines mods which enhance the default possibilities of the game's traffic simulation. Mod Network Extensions extends the list of road types that can be used in the game. Mod Roundabout Builder provides a simple and efficient tool for building a roundabout of any size and road type. Mod Real Time enables a realistic change of day and night and modifies the behaviour of the agents accordingly. Using this mod, traffic peaks can be observed in the modelled road system. The 'must have' mod, when simulating traffic in Cities: Skylines is the mod Traffic Manager: President Edition (TMPE). This mod adds to the game a wide range of tools to control the traffic as well as various enhancements to the simulation logic (TM:PE V11 STABLE, 2020). The tools allow the player to toggle traffic lights at a junction, configure set of steps for a traffic light, control the lane transition, set priority roads and give way signs, set junction rules, set speed limits and vehicle restrictions on roads or forbid parking. Majority of these tools were used to configure the road network of the Olomouc model. Beside the added tools, TMPE also enhances the game's traffic simulation logic to increase the simulation realism. The enhancement options – in the mod's menu can be turned on or off - include an improved path finding cost calculation scheme, a lane selection algorithm allowing to switch to an alternative lane while en route, and enforcing parking by disallowing "pocket cars" (situation when a car appears from nowhere for a citizen who is starting a trip) (Traffic Manager: President Edition Documentation, 2019).

In order to monitor the traffic in Cities: Skylines, I created a mod SegmentMonitor. The main class of this mod, SegmentMonitorThreading, inherits from game's API class ThreadingExtensionBase. Using the inherited method OnUpdate(), which is triggered at every simulation step, the mod exports the traffic usage of segments in the game into a CSV file. The export is done every 15 minutes of the game time (using a Real Time mod is highly recommended) and added to the CSV file. The usage of a segment is taken from the parameter m_trafficDensity that represents the number of cars driving through a segment at the monitored moment. Two exports are done, one for each individual segment and anther one for whole roads (segments are grouped by road name). To prevent extensive logging that slows down the whole game, the segments are filtered based on traffic density and length. Segments that are too short or have small traffic density are filtered out. The mod automatically starts monitoring the segment usage after loading a model and will stop when the model or the game is exited. The aim of the monitoring was to identify parts of the model's road network with the worst traffic. The game's traffic info view provides visual output of the traffic density. In the model of Olomouc, the overall traffic density ranges between 76% and 82%. Figure 7 shows the visual output of the traffic density in the model of Olomouc.

Figure 7 Traffic info view for the model of Olomouc.

Using the game's traffic info view, problematic parts of the road network can be easily spotted. However, to exactly identify the busiest roads in the model, the road network was monitored using the SegmentMonitor mod. The model of Olomouc was started in the early morning hours of the game time and was left running for a whole game day. During this time, the mod SegmentMonitor was recording the segment's traffic density every 15 minutes. When the monitoring was finished, the exported file RoadMonitor.csv was opened in MS Excel. The records were sorted by road name which grouped every 15 minutes of monitoring under the same road record. Next, using the function subtotal, a sum of values of the column AvgDens for each road was calculated. The column AvgDens represents average density of the road. It is calculated as a sum of m_trafficDensity of each segment divided by the number of segments of the road. The sum of average density was preferred in this case because the filtering mechanism of the SegmentMonitor mod produces inconsistent number of road records (i.e. using the average operation would favour roads where the traffic density peaked once over roads where the traffic density is consistently high). Finally, the road name and their subtotals were ordered from highest to lowest to produce the final list. The resulting sum of average density in this case serve only as an indicator of high traffic density. The Table 3 lists the 20 busiest roads in the model of Olomouc. Roads without a name are marked with either the game's generated name in English or with the 'No Name' prefix generated by the GeoSkylines mod. In these cases, the column Notes describes the location of the road.

In order to compare the simulated traffic data from the model of Olomouc to real traffic situation in the Olomouc area, the authentic traffic data were monitored using the HERE Traffic API. The HERE Traffic API is a REST API that provides the information about traffic flow and incidents on the roads (HERE Traffic API, 2021). The API is called via URL request with parameters apiKey, bbox and responseattributes. For the parameter apiKey I used my personal API key generated on the HERE Developers platform. The parameter bbox is a spatial filter of the request. It represents a rectangular area specified by two latitude/longitude pairs (the top-left corner and the bottom-right corner of the bounding box). The same bounding box, which was used for recreating the Olomouc area in Cities: Skylines, was used for requesting the authentic traffic data. The parameter responseattributes was set to 'shape'. This way the response provided a list of latitude and longitude coordinates defining the geometry of the roads as well. The response is a structured XML file containing roads from the specified bounding box and their attributes. The most important attributes for this research were DE, which is the text description of the road, PBT which is the time when the traffic data were recorded, and JF which is a number between 0 and 10 indicating the expected quality of travel.

Table 3 10 busiest roads in the model of Olomouc.

Road Name	Sum of AvgDens	Notes
U podjezdu	5678.5	
No Name 4052	4178.9	I/46 near Dolany
Svatoplukova	3906.8	
Hickory Street	3852.7	I/46 near Týneček
Raymond Street	3529	connection from Brněnská to Velkomoravská
Rolsberská	3452.2	
Price Street	3207	roundabout at Dobrovského
No Name 4742	2937.3	roundabout at Týnecká
Holická	2802.1	
Dr. Milady Horákové	2774.3	

I developed a Python script to convert the received XML file into a GeoPackage layer (using the GDAL library). This script creates the road records, creates the line geometry from collected latitude and longitude coordinates, renames the attributes (e.g. JF to Jam_Factor) and stores the attribute values. Additionally, the Python script includes a mechanism to call the API request repeatedly in a specified time interval.

The traffic data were monitored on Thursday 1st of October. The Python script was started on 30th of September 2020 after 10pm and kept running through late night hours of 1st of October 2020, requesting data from HERE Traffic API every 15 minutes. The collected data were later filtered to include only records from the time frame 1st of October 5 am to 1st of October 9pm. For this task, the time from the attribute PBT was considered and not the time when the request was called. Each request created a new layer in the GeoPackage dataset. To further analyse this data, all layers were merged into one. An additional attribute time was created to store the value of the attribute PBT in a more suitable format. To find the busiest roads, the merged GeoPackage layer was exported into a CSV file. After opening the CSV file in MS Excel, the data were ordered by the attribute Road_Description. Next, using the subtotal function, an average of values of the attribute Jam_Factor was calculated for each road. Finally, the road name and their subtotals were ordered from highest to lowest to produce the final list. The Table 14 lists the roads with the highest Jam_Factor (roads affected by the construction work near street Masarykova třída were excluded).

Table 4 10 busiest roads according to monitoring of authentic traffic in Olomouc on 1st of October 2020.

Rank	Jam_Factor	Road_Description
1	3.11	Studentská
2	3.06	tr. Svobody
3	3.02	Komenského
4	2.87	17. listopadu
5	2.75	Husova
6	2.71	Pavlovická
7	2.70	Palackého
8	2.54	Legionárská
9	2.46	Hynaisova
10	2.46	tr. Kosmonautu

The traffic density measured in the game and the jam factor provided from the HERE Traffic API, are calculated differently. Also, the roads are represented differently in both systems. Therefore, the comparison cannot be absolute. Nevertheless, monitoring of the traffic data provided a general idea of the most problematic parts of the road network in both systems. Figures below offer a visual comparison of the traffic density in the simulated data (Figure 8) and the authentic traffic data (Figure 9). In both cases, the function Natural Breaks (Jenks) was used to set the range of the monitored attribute.

Even by a simple visual comparison, we can see that both the simulated and the authentic traffic data identify similar issues of the road network: the roads near industrial zones in the districts Bělidla and Pavlovičky (Hodolanská, Pavlovická, Chválkovická, U Podjezdu, Roháče z Dubé), the intersection of Lipenská and Tovární, the main roads in the district Holice (Rolsberská and Přerovská) and the speed road Velkomoravská. However, the model simulates higher traffic on roads Erenburgova, Svatoplukova and Dr. Milady Horákové than the authentic traffic data suggest. On the other hand, the model simulates lower traffic on roads Studentská, tř. Svobody and Kosmonautů.

The comparison of the Table 12 and Table 14 provides more detail. The busiest roads according to the authentic traffic data (such as Studentská, tř. Svobody or tř. 17 listopadu) are not recognized by the simulation as the busiest. The busiest roads according to the simulation are often roads that serve as a connection to industrial zones (U podjezdu, Roháče z Dubé, Svatoplukova). This simulation result is likely caused by the game's exaggerated demand for supplies of the industrial zones. The high demand then generates a high amount of freight vehicles. To mitigate this behaviour, the industrial zones can be made smaller in the model.

Figure 8 Roads, exported from the model of Olomouc and imported into QGIS, and their traffic density.

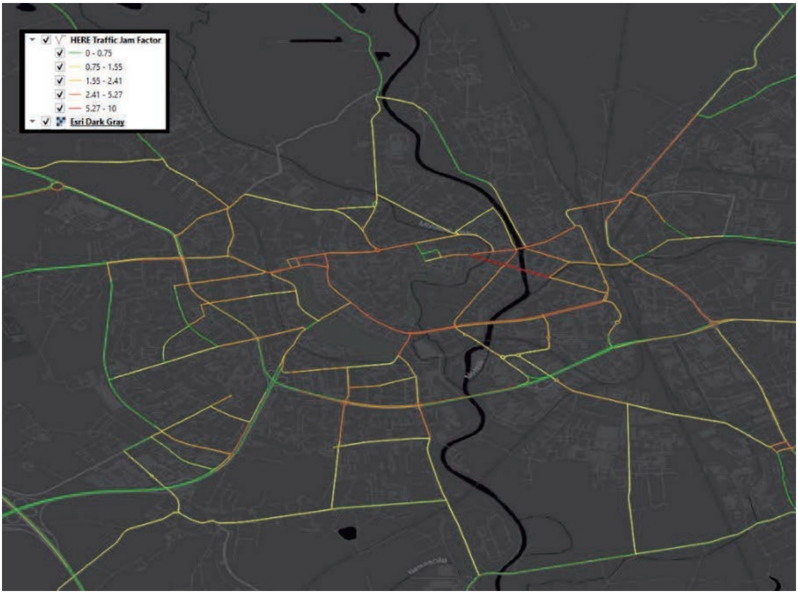

Figure 9 Roads of Olomouc and their jam factor according to HERE Traffic API, monitored on 1st of October 2020.

Other inaccuracies of the simulation might be caused by imperfections of the model or the nature of the agents (i.e. perfect driving without accidents). For example, in the model, the cars heavily use the road Dr. Milady Horákové while in reality many drivers see this road as problematic and try to avoid it (though it is still used considerably). The difference factor in this case might be in fact minor: while complicated connection from Masarykova třída and the narrowness of the road prevents some drivers from taking this road, the simulated cars, not fearing any accidents, see this road as any other road and decide to take it. The inaccuracies of the traffic simulation can be mitigated by updating the model. In the case of the road Dr. Milady Horákové, a speed limit can be lowered on this road. The agents will then start favouring other routes. This effect was tested when configuring the model of Olomouc for the traffic simulations. Initially, the traffic in the historic centre was quite high as the roads were seen by the agents as standard roads which often provided the shortest path to their destination. However, simply adding speed limits, the agents started favouring other roads and thus the heavy transit traffic was prevented.

Aside from simulating the traffic density in the whole model of Olomouc, two scenarios were tested as well. First scenario - demolishing a bridge connecting roads Komenského and Pasteurova – represents a real reconstruction of this bridge in years 2019 and 2020. This bridge is an important part of a route navigating the traffic out of the city centre to Pavlovičky and then outside the city of Olomouc. Second scenario – constructing a highway bypass connecting arterial roads D/55, D/35 and I/46 – represents a planned development in this area (Silnice I/46 Olomouc – Východní Tangenta, 2021; Silnice I/46 Týneček – Šternberk, 2021).

For the first scenario, after removing the bridge, the traffic density increased significantly on the roads Dr. Milady Horákové - from 45.5% to 59.7% - which serves as a connection to the road Pavlovická (access to industrial zones and exit from the city) and Masarykova třída – from 8.9% to 30% - which became the only exit road from the historic centre. The traffic density increased also on a small road Jiřího z Poděbrad – from 22.6% to 29% - which redirects most of the traffic from the road Dobrovského. Some cars tried to utilize side roads such as Nábřeží – from 3.7% to 24.7% - and Kaštanová – from 9.4% to 12.7% - which connects roads Dr. Milady Horákové and Pasteurova (leads to U podjezdu and Chválkovická).

For the second scenario, a highway bypass had to be constructed in the game according to the planned developments. After recreating the highway bypass, the simulation was left running for several minutes for the game to recalculate the routes. Figure 10 shows the stabilized states of the traffic simulation before constructing the highway bypass (left) and after constructing the highway bypass (right). To achieve the best comparison, the function Equal Interval was used to set the range of the monitored attribute for both datasets.

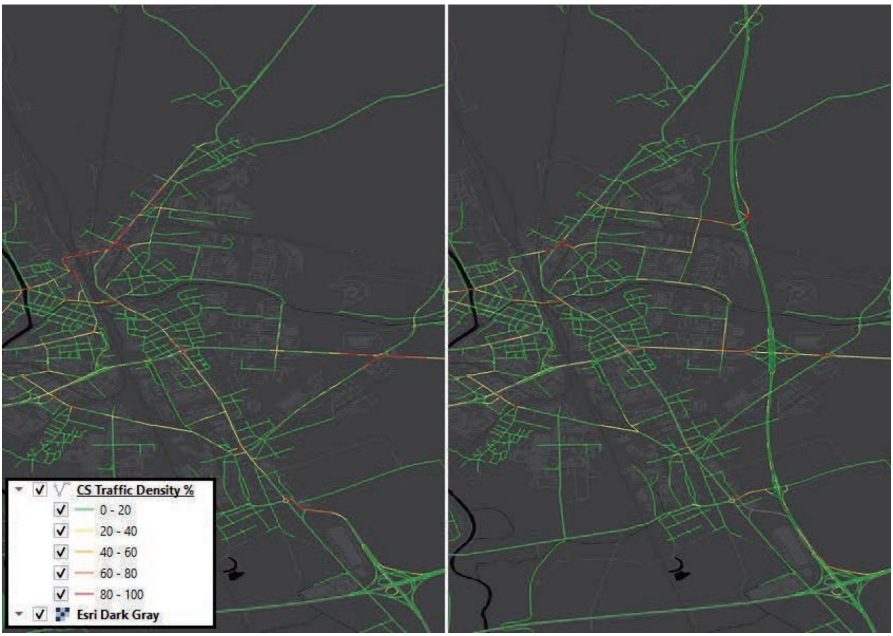

Figure 10 Comparison of roads, exported from the model of Olomouc and imported to QGIS, and their traffic density before (left) and after (right) constructing the highway bypass.¨

8. Discussion

This section discusses achieved results of the thesis, the encountered challenges, recommendations, and possible improvements to any future research which applies a city-building game in spatial planning.

Modelling in Cities: Skylines

In Objective 1, the game Cities: Skylines was selected as a game with the highest potential for its application in spatial planning. The reasons why this game was selected were sufficiently validated during the research. Among numerous great features of the game, the game's graphic environment, based on Unity 3D, offers vast possibilities for recreating a real-world place. The game's area 17.28 km x 17.28 km x 1 km provided enough space for recreating the city of Olomouc without any spatial distortion. The most important feature of Cities: Skylines is its extensive modding environment, consisting of API written in C# and the modding documentation (tutorials, user forums, available source codes of existing mods, etc.). According to the game publisher, more than 175,970 mods have been already published on the platform Steam (Cities: Skylines Celebrates Fourth Anniversary and Six Million Copies Sold, 2019). Numerous mods were also used for the creation of the model of Olomouc and for modifying the model's behaviour to achieve the desired results. Moreover, the modding environment was used in this research to develop two new mods for processing geodata and for monitoring the traffic density. Without the modding environment, conducting this research would not be possible.

Nevertheless, the use of the game Cities: Skylines in this research was not always smooth and easy. The game itself is difficult for new players (after all, the objective of the game is nothing less than to build and manage a city with all its processes). Therefore, very good knowledge of the game is highly recommended when using it in a research. The game's biggest strength, the modding environment, could also present a risk if badly managed. Installing various mods e.g. for enhancing the visual accuracy of the model or for supressing unwanted behaviour is tempting. But when the number of mods used for a model increases significantly, their management might become very problematic. In worst case scenario, when two or more mods modify the same functionality of the game, the model can get corrupted and unusable. The main tool for managing mods is the platform Steam. A developer uploads his mod to Steam where other players subscribe to it. Steam then installs the mod into the game and manages further updates. Steam is highly sufficient for managing individual mods. The problem occurs when managing multiple mods, especially mods conflicting with each other or conflicting with new updates of the game. There are also mods that are no longer working but are still present on Steam. For this case, members of the gaming community maintain a list of obsolete mods that should be avoided. Many moders follow a good practice of including information about conflicting mods to their mod description. Despite the great efforts of the gaming community to help with this problem, the best option would be to include sensible mod management directly into the game. At this moment, there is no official tool for managing mods, thus the user must do this him/herself – properly read the mod description, find out about possible conflicts, decide whether it is really required or not, etc.

As for data processing, uploading terrain into the game via the map editor is the only inbuilt option. To import road network into the game, the player can install one of few mods available on Steam. GeoSkylines, mod developed in this research, enables import of other geographical data as well (water basins, trees, zoning, etc.). The GeoSkylines mod aims to provide a standardized way of processing geodata. The mod does not pre-process the geographical datasets. This must be done beforehand by the user (the mod's step-by-step documentation provides examples of data pre-processing). Though this feature decreases the user-friendliest of the mod as it requires some knowledge of GIS, it allows the user to update the data before importing them into the game (filtering, renaming the attributes or updating the attribute values). Competitive mods available on Steam have the processing of OSM road data embedded in them and thus do not allow further changes to the input data. Numerous challenges occurred during the development of the mod GeoSkylines. Curved geographical roads defined by multiple short narrow segments represented one of the biggest challenges, as importing them into the game created a large number of segments and nodes. Though such generated road network was correctly topologically connected, it caused graphic glitches, unwanted traffic patterns and breaching the game limits of created segments and nodes. The solution to this issue was implementing Bézier curves functionality into the road import method. Furthermore, this functionality had to be combined with preserving the junction nodes and splitting excessively long segments. A challenge that was not resolved during the development of the mod was implementing an elevation to the road import. Although several attempts were made, none of them presented satisfying results and thus were not included in the final solution. The challenges during the programming of the GeoSkylines mod are described in section 6.7. Despite all the possibilities that GeoSkylines or similar mods offer, there is undoubtedly still space for improvements for data processing. Ideal scenario which Cities: Skylines, or any other city-building game, should aim for is the example of Minecraft where a professional data processing tool FME can be used for importing and exporting data to or from the game (Boudník, 2020).

Some city-related processes simulated in Cities: Skylines demonstrate unrealistic behaviour. Most notably, this is the case of exaggerated demand for services. This behaviour was introduced into the game to create a challenge for the player even in the early stages of building a city. E.g. city with a population of 500 requires a fire and police station and an elementary school. When creating the model of Olomouc, a city with a population over 100 thousand, the exaggerated demand for services became unmanageable. The city required tremendous amounts of electricity, water, garbage collectors, firefighters, etc. The unwanted behaviour was mitigated or completely supressed by installing mods such as No Fires, No Need for Pipes, Pollution Remover or custom assets such as Large water station or solar panels producing large amount of electricity. Though the installed mods helped to resolve these issues (again underlining the importance of the modding environment), the best option to manage the simulation accuracy would be a tool provided directly in the game. Such tool would remove the need for installing numerous mods and greatly improve the game's use for conducting simulation scenarios.

Despite the limitations mentioned above, the game Cities: Skylines demonstrated many qualities in this research and is more than suitable for conducting a study involving city-building games. However, a good knowledge of the game and the modding environment is required for conducting a research involving this game. Due to its limits, the game is optimal for modelling cities up to 200 thousand population. Beyond this point the model could reach the limits of created game objects or simply not fit in the available game area. For bigger cities, modelling only a part of the city is recommended.

Gamified approach to geo-participation

As part of Objective 4, the model of Olomouc was utilized for a design contest of a new neighbourhood VOP Velkomoravská. The objective of this event was to gather creative ideas for utilizing one of the most valuable brownfields in the city of Olomouc as well as to set a methodology for running a design contest involving a city-building game. The design contest was organized in five stages: preparing the design rules; starting the design contest; collecting designs and creating the presentation material; assessing the designs and finally gathering feedback from the players and the jury. At the beginning, it was uncertain how many players will participate in the design contest. To prevent lack of interest, the contest had to present a compelling challenge to the players and be well propagated. The event was initially advertised on a Reddit forum dedicated to Cities: Skylines and on social media. Then a reminder of the event was posted on Reddit every day. Furthermore, some of the players started to share the link to the original post which helped with the propagation greatly. The interest is indicated by the number of subscriptions, currently 38, to the starting model of Olomouc which was published on the platform Steam (Pinos, 2020c). In the end, ten designs were submitted, which provided plenty of material for running a contest. Overall, the interest for the VOP Velkomoravská design contest was higher than expected, especially given the fact that this event was not organized by an institution (e.g. the city) and thus could not offer interesting prizes or other perks to the contestants.

After the contest, a feedback from the players as well as from the members of the jury was gathered. The players were asked mostly about the design contest. According to their responses, there were no technical obstacles in installing the starting model, downloading the support materials, and submitting the final design. The biggest obstacle presented the design rules, which the respondents considered rather strict (out of 7 responses, 3 considered the rules strict, 3 as neutral and 1 as not strict). This is in contradiction with the responses from the jury regarding design rules. The judges considered the design rules not as sufficient (out of 3 responses, 2 considered the rules as not sufficient, 1 as sufficient). Moreover, the city representative pointed out that an important condition of the city's masterplan - downgrading speed road Velkomoravská to a calmer urban road with connections to the neighbourhood – was missing among the design rules, which affected some of the designs that treated the Velkomoravská road as a barrier. This error happened during the preparation of the design rules. In an attempt to simplify the rules by selecting the most important conditions from the masterplan, the development plans for the street Velkomoravská were omitted. The feedback regarding the design rules from both the players and the judges suggest that the preparation of the rules is possibly the most important part of the whole design contest. The design rules must find the optimal balance between playful – so it is compelling to players – and professional – so it can be accepted by experts in the field of spatial planning. The rules should follow the conditions for the modelled area stated in the city's masterplan, but a simplification of these conditions is recommended to attract players. The simplification can reword the original conditions, set priorities to the conditions, or completely exclude some conditions if they are not decisive for the design outcomes. However, the simplifications should be discussed with the city representatives or, ideally, prepared by a city representative. The city representative can decide which conditions to include or exclude from the design rules.

A video presentation was created for all the collected designs. This helped to increase the comparability among designs as well as to avoid possible technical difficulties when starting the models in the game. The videos were structured similarly (depending on the amount of information provided), presenting in succession aspects of the designs: road network and transport, housing, leisure, shops and services, connection to adjacent areas and within the neighbourhood, and flood protecting measures. Despite the video presentations, the jury still found it difficult to compare the designs. According to comments from the judges, the rules should include more criteria such as budget or expected population for a better comparability of the designs. Both criteria can be measured in Cities: Skylines, so adding them to any future design contest is recommended. Other option for improving the comparability could be a unified form for presenting the results (same structure, aerial snapshots taken from the same angles, etc.). Ideal but more distant option for improving the comparability would be a tool that allows viewing a simplified version of the model (e.g. a static extract). At the moment there is no such tool available, but with the increasing interest in organizing design contests in Cities: Skylines it might be a matter of time before it is created by the game developers or the modders. Feedback was also gathered regarding the general use of Cities: Skylines in spatial planning. One player cannot see the game be used as a professional tool for spatial planning due to its limitation but believes the game can be used for observing traffic patterns and visualizing designs. The judges see the game's biggest potential being used as a tool for inspirational and critical thinking while the other uses see as conceivable but with some limitations.

The VOP Velkomoravská design contest presented a novel way of geo-participation where players of a city-building game were asked to design a new neighbourhood. Submitted designs from players who accepted the challenge demonstrated wide range of innovative ideas and different approaches to spatial planning. According to the player's feedback, most of them do not have expertise in spatial planning or similar fields such as GIS. Despite this fact, they were able to use the game model to plan and develop a whole new neighbourhood with all its relations.

The description and the results of the contest were published in a local magazine and the web portal of the city of Olomouc (Možnou Budoucí Podobu Nové Olomoucké Čtvrti Navrhovali Hráči z Celého Světa, 2021; Studenti ve Hře Řešili Návrh Nové Čtvrti Na Velkomoravské, 2021). Additionally, this case study proposed a methodology for organizing a design contest involving a city-building game.

Using a game as a simulation tool

The game Cities: Skylines offers numerous simulations and thus could be considered for a use as a simulation tool as well. City-building games, including Cities: Skylines, demonstrate many simplifications of the simulation processes which are often criticized (Bereitschaft, 2016). On the other hand, the modding environment in modern games help to mitigate or completely overcome these limitations. This is also the case of traffic simulations in Cities: Skylines. Although traffic simulation in this game is arguably the best in the city-building game genre, the simulations still incorporate many simplifications in order to lower the computational load or prevent extensive complexity (Lehto et al., 2015). Numerous mods were created to modify the traffic simulations in the game, most notably Traffic Manager President Edition (TMPE). This mod offers multiple tools for managing the traffic as well as enhancing the simulation logic.

As part of Objective 4, the traffic density was monitored in the model of Olomouc. The model of Olomouc was configured to represent the road system as accurately as possible (appropriate population, zoning, types of roads and junctions, road rules, etc.). Next, the traffic density was monitored in the whole model. To draw a comparison, authentic traffic data were monitored as well (using the HERE Traffic API). The comparison pointed out similarities but also differences in the traffic patterns. Whereas both systems identified similar parts of the road network as problematic, the overall traffic density in the game was higher. This is caused by the game's exaggerated demand for services which generates high number of freight vehicles. Therefore, the busiest roads according to the game simulations are near the industrial zones. To mitigate this behaviour, the industrial zones can be made smaller (e.g. by adding gaps to the blocks zones as industrial). The optimal solution would be setting the level of demand of the services requesting industrial goods by using an inbuilt tool or a mod. The traffic density was also monitored for specific scenarios inspired by past or future developments. First scenario involved demolishing a busy bridge on the route from the city centre to the outer parts of the city. The second scenario involved creating a highway bypass connecting three arterial roads to prevent transit traffic going through the city. In both cases, the simulation presented expected results. The second scenario confirmed the benefit of constructing the highway bypass by diverting the transit traffic from the city parts Holice, Hodolany, Bělidla and Pavlovičky.

The changes in the model's traffic patterns during the day were tested as well. The mod Real Time mimics the day-night cycle and introduces traffic paters depended on the time of the day (i.e. rush hours). Analysing the monitoring data confirmed that there are changes in the overall traffic density during the day, but the changes were much lower than anticipated (i.e. the overall traffic density was ranging from 78% - 82%). The description of the Real Time mod offers possible explanation of the rush hour's low effect on the overall traffic density: the mod works best for cities under the population of 65 thousand. For a model of a city with population 110 thousand, the simulation of the Real Time mod was not as efficient as expected. Because of this reason, the changes of the traffic patterns during the day were not analysed. Nevertheless, the use of the Real Time mod is recommended for implementing the realistic day-night cycle. Additionally, this mod might prove great benefit when simulating traffic in smaller cities. In order to conduct a traffic simulation study in Cities: Skylines, first the real-world area must be modelled in the game. The difficulty of this task is dependent on the solver's knowledge of the game and its modding environment. However, when the model is complete then modifying it using the inbuilt tools, e.g. for simulating scenarios, is easy. The TMPE mod offers several options for enhancing the game's traffic simulation logic including improved path finding cost calculation scheme, enforced parking, or a lane selection algorithm allowing to switch to an alternative lane while en route. The model of Olomouc used moderate setting of these options (to use the strictest setting, a model must represent the reality almost in 1:1 ratio). On the other hand, it can be argued that the inaccuracies in the traffic simulations are balanced by the lack of car accidents and reckless behaviour of the car agents. Despite the found inaccuracies in traffic simulation, the game Cities: Skylines can be applied as an experimental simulation tool, in schools for education, by enthusiasts or even by city planners. The game allows to quickly modify the road network and observe the change in traffic patterns almost immediately. Moreover, the possibility to modify the code of the simulations – either by updating the source code of the TMPE mod or writing a new separate mod – allows a professional use of the game for traffic simulations.

9. Conclusion

The processes of spatial planning are often very complex and involve many stakeholders. Games started to be utilized in spatial planning as an education tool but lately also as a tool for simulation, visualization, and engagement of the general public. Therefore, this dissertation thesis explores the possibilities of applying a city-building game in spatial planning.

In Objective 1, the game Cities: Skylines have been selected as the game with the highest potential for its use in spatial planning. This game offers 3D environment enabling the modelling of a real-world place, wide range of simulations of city-related processes and most importantly an extensive modding environment that allows modifying the game's looks and behaviour. Additionally, this game has been used previously in spatial planning.

In Objective 2, a new game mod named GeoSkylines was developed in the game's API. This mod consists of approximately 4000 lines of code written in programming language C#. This mod offers 15 callable methods (9 import, 4 export and 2 helper methods) that create game roads, railways, trees, water basins, services and zoning based on the source geographical data, or export game roads, railways, buildings, trees and zones as geographical data. The mod uses a simple CSV format to store the geographical data with its geometry written in a WKT format. WGS 84 was used as a default coordinate system to store the geographical data. The game's custom coordinate system could be considered as a variation of UTM. Therefore, the conversion of geographical coordinates to game coordinates and vice versa is based on a standard conversion algorithm between the coordinate systems WGS 84 and UTM. The mod GeoSkylines was published on the platform Steam where players can subscribe it (this action will install the mod into the game and manage further updates). The mod is currently subscribed by 285 users who use it for recreating a real-world place of their choosing.

In Objective 3, a model of the city of Olomouc was created from geographical data in the game Cities: Skylines. First, datasets for road network, water resources, tree coverage, zoning and services were prepared. OSM was used as a main data source, supplemented by various local data sources. Next, the prepared geographical datasets were imported into the game using the GeoSkylines mod. This a way a base model of Olomouc was created. Last, the model was updated manually (post-processing). This step involved fixing data related issues but also mitigating or completely supressing unwanted behaviour of the game model in order to achieve the set goals of the research. As a result, a playable model of the Olomouc area was created. This area includes the city of Olomouc as well as 25 surrounding small towns (the modelled area covers majority of the Olomouc municipality boundary).

In Objective 4, the model of Olomouc was utilized in two case studies. First case study was a geo-participation project, where players were asked to design a new neighbourhood in the model of Olomouc. The selected area is a former military compound, referred in the city's masterplan as VOP Velkomoravská. This case study happened in five stages: preparing the design rules; starting the design contest; collecting designs and creating the presentation material; assessing the designs and finally gathering feedback from the players and the jury. The submitted designs (11) demonstrated wide range of innovative ideas and different approach to spatial planning. In the second study case, the model of Olomouc was used for simulating traffic density. First, the traffic density was monitored in the whole model. The results of this monitoring were then compared to authentic traffic data (using HERE Traffic API). Both monitoring identified similar problematic parts of the road network in the city of Olomouc. Additionally, the traffic density was monitored for two scenarios: demolishing a bridge and constructing a highway bypass. In both cases, the simulation presented expected results. The second scenario confirmed the benefit of constructing the highway bypass by diverting the transit traffic.

10. Literature

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11. Shrnutí

Procesy územního plánování jsou často velmi složité a zahrnují mnoho zúčastněných stran. Hry se začaly využívat v územním plánování jako vzdělávací nástroj, ale v poslední době také jako nástroj pro simulaci, vizualizaci a zapojení široké veřejnosti. Tato disertační práce proto zkoumá možnosti uplatnění hry budování města v územním plánování.

V rámci dílčího cíle DC1 byla vybrána hra Cities: Skylines jako hra s nejvyšším potenciálem pro její využití v územním plánování. Tato hra nabízí 3D prostředí umožňující modelování skutečného místa, širokou škálu simulací procesů souvisejících s městem a co je nejdůležitější, rozsáhlé modifikační prostředí, které umožňuje upravit vzhled a chování hry. Tato hra byla navíc dříve používána v územním plánování.

V rámci dílčího cíle DC2 byl v herním API vyvinut nový herní mod s názvem GeoSkylines. Tento mod se skládá z přibližně 4000 řádků kódu napsaných v programovacím jazyce C #. Tento mod nabízí 15 volatelných metod (9 pro import, 4 pro export a 2 pomocné metody), které vytvářejí herní silnice, železnice, stromy, vodní nádrže, služby a zónování na základě zdrojových geografických dat nebo exportují herní silnice, železnice, budovy, stromy a zóny jako geografická data. Mod používá jednoduchý formát CSV k ukládání geografických dat s jejich geometrií napsaných ve formátu WKT. WGS 84 byl použit jako výchozí souřadnicový systém pro ukládání geografických dat. Vlastní souřadnicový systém hry lze považovat za variaci UTM. Proto je převod zeměpisných souřadnic na souřadnice hry a naopak založen na standardním algoritmu převodu mezi souřadnicovými systémy WGS 84 a UTM. Mod GeoSkylines byl publikován na platformě Steam, kde si hráči mohou přihlásit jeho odběr (tímto se nainstaluje mod do hry). V současné době se k odběru modu přihlásilo 285 uživatelů, kteří jej používají k vytvoření reálných míst podle svého výběru.

V rámci dílčího cíle DC3 byl z geografických dat vytvořen model města Olomouce ve hře Cities: Skylines. Nejprve byly připraveny datové soubory pro silniční síť, vodní zdroje, pokrytí stromů, územní plánování a služby. Jako hlavní zdroj dat byl použit OSM doplněný o různé místní zdroje dat. Dále byly připravené geografické datové sady importovány do hry pomocí modu GeoSkylines. Tímto způsobem byl vytvořen základní model Olomouce. Nakonec byl model aktualizován ručně (post-processing). Tento krok zahrnoval řešení problémů souvisejících s daty, ale také zmírnění nebo úplné potlačení nežádoucího chování herního modelu za účelem dosažení stanovených cílů výzkumu. Díky tomu byl vytvořen hratelný model olomoucké oblasti. Tato oblast zahrnuje město Olomouc i 25 okolních malých měst (modelovaná oblast pokrývá většinu hranice města Olomouce).

V rámci dílčího cíle DC4 byl model Olomouce použit ve dvou případových studiích. První případovou studií byl projekt geo-participace, kde byli hráči požádáni, aby navrhli novou čtvrť v modelu Olomouce. Vybraným územím je bývalý vojenský prostor, který se v územním plánu města označuje jako VOP Velkomoravská. Tato případová studie proběhla v pěti fázích: příprava pravidel návrhu; zahájení soutěže; sbírání návrhů a tvorba prezentačního materiálu; posouzení návrhů a nakonec získání zpětné vazby od hráčů a poroty. Předložené návrhy (11) demonstrovaly širokou škálu inovativních nápadů a odlišných přístupů k územnímu plánování. Ve druhém studijním případě byl pro simulaci hustoty provozu použit model Olomouce. Nejprve byla v celém modelu monitorována hustota provozu. Výsledky tohoto monitorování byly poté porovnány s autentickými daty o provozu (pomocí HERE Traffic API). Obě monitorování identifikovaly podobné problematické části silniční sítě ve městě Olomouc. Doplňujícím výzkumem bylo monitorování hustoty provozu u dvou scénářů: demolice mostu a vybudování dálničního obchvatu. V obou případech simulace představila očekávané výsledky. Druhý scénář potvrdil výhodu výstavby dálničního obchvatu který napomohl odklonit tranzitní dopravu.

Curriculum vitae

Personal data	**Name:** Ing. Jan Piňos **Email:** pinosjan@gmail.com
Education	*2016 – today*: PhD studies, Faculty of Science Palacký University Olomouc, field Geoinformatics and Cartography *2001–2007:* masters studies, Faculty of Mining and Geology Technical University of Ostrava, field System Engineering
Practice and Experience	**GIS specialist at Vector Limited, Auckland, NZ** 2012 - today **Summer school GIS/Lidar - UPJŠ Košice** *07/2019,* summer school participant **GeoSpatial Summer School 2019** *06/2019,* summer school participant **Výzkum a aplikace metod geoinformatiky pro řešení prostorových jevů reálného světa – IGA_PrF_2019_014** *2019–2020,* project lead **Inovativní metody hodnocení a pokročilé analýzy prostorově založených systémů – IGA_PrF_2018_028** *2018–2019,* member of the project team **Cloudová platforma pro integraci a vizualizaci různých typů geodat – IGA_PrF_2017_024** *2017–2018,* member of the project team **Smallworld developer at Tieto Czech s.r.o., Ostrava** *2007 – 2010* **Smallworld consultant at we-do-IT (NZ) Limited, Auckland, NZ** *2011 – 2012*

Overview of author's activity during his study

Study duties

As a part of study duties, the student passed seven mandatory doctoral exams, completed three months of research abroad and participated in teaching lectures.

Passed exams

Ac. year	Subject	Date
2016/2017	PRF/PGS00 Scientific and research management	09.11.2016
2016/2017	VCJ/PGSAJ English for PhD students (C1)	09.12.2016
2016/2017	KGI/PGSOO Object oriented technologies (doc. Dvorský)	12.06.2017
2017/2018	KGI/PGSVS Software development in open source GIS (prof. Hofierka)	22.11.2017
2017/2018	PRF/PGS01 Research internship abroad	02.03.2018
2017/2018	KGI/PGSSA Service Oriented Architecture in Geoinformatics (doc. Pechanec)	12.7.2017
2019/2020	KGI/PGSMS Modelling and simulation of spatial phenomena (prof. Voženílek)	28.01.2020

Completed research internships

Ac. year	Institution	Description
2017/2018	Vector Limited, New Zealand – private company.	During this internship, the student explored practical options of Extract Transform Load (ETL) solutions. Focus was given to commercial product FME and open source library GDAL. The student developed several scripts for converting and transforming geographical data using both researched products.

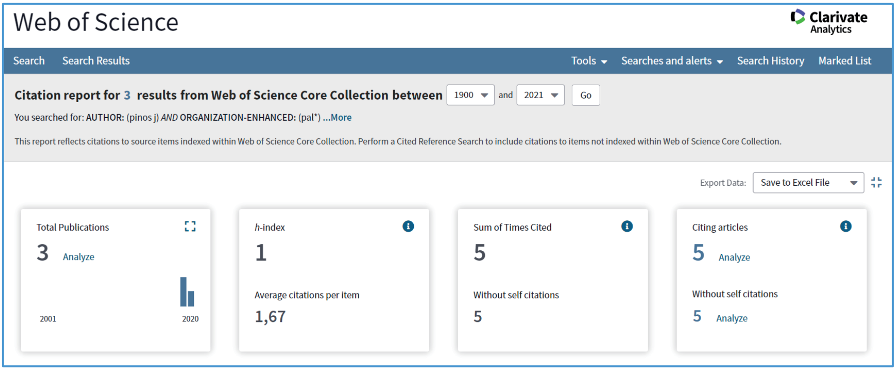
Teaching overview

During the doctoral study, the student contributed to teaching in several subjects:

- 2016/2017 KGI/DATAS
- 2016/2017 KGI/DYWE
- 2017/2018 KGI/DYWE
- 2018/2019 KGI/PRG1

Publications

The author's publications follow the requirements of the doctoral studies and the requirements of the research activities of the Department of Geoinformatics at Palacký University Olomouc.



Publications related to the thesis

Domestic publications

Ac. year	Category	Citation
2018/2019	Jrec	**Piňos, J.** (2019). Současné trendy využívání vážných her a videoher v oboru urbánního plánování. Kartografické listy, 27 (1), 14-24. (anglicky)

International publications

Ac. year	Category	Citation
2019/2020	Jimp 1.8	**Pinos, J.**, Vozenilek, V., & Pavlis, O. (2020). Automatic Geodata Processing Methods for Real-World City Visualisations in Cities: Skylines. ISPRS International Journal of Geo-Information, 9(1), 17. **WoS/Scopus**

Domestic conferences

Ac. year	Conference name	Citation
2018/2019	GIS Ostrava 2019	**Pinos, J.** (2019) Využití simulačních her pro řešení problémů urbánního prostoru. GIS Ostrava 2019

International conferences

Ac. year	Conference name	Citation
2018/2019	FMG 2019, Zvolen	**Pinos J.** (2019) The use of games in the field of urban planning. FMG 2019, Zvolen

Other published work

Domestic publications

Ac. year	Category	Citation
2017/2018	Jrec	Dobešová, Z., **Piňos, J.** AUTOMATICKÁ TVORBA KARTODIAGRAMU VĚKOVÉ PYRAMIDY, Kartografické listy, 26(1), pp. 3-9, Kartografická spoločnost Slovenskej republiky, Bratislava, Slovensko, 2018, ISSN 1336-5274 (In Czech)

International publications

Ac. year	Category	Citation
2018/2019	Jimp 1.6	**Pinos, J**., & Dobesova, Z. (2018). ATTA Converter: software for converting data between ArcGIS and TerrSet. Earth Science Informatics. Springer. **WoS/Scopus**
2017/2018	D	Dobesova, Z., & **Pinos, J.** (2018). Using decision trees to predict the likelihood of high school students enrolling for university studies. COMESYSO. Springer. **WoS**
2018/2019	D	Dobesova, Z., & Paszto, V., & **Pinos, J.** (2018). Association of innovations with the enterprise group membership. Knowledge For Market Use. **WoS**

Domestic conferences

Ac. year	Conference	Citation
2018/2019	Knowledge for Market Use 2018, Olomouc	Dobesova, Z., & Paszto, V., & **Pinos, J.** (2018) Association of innovations with the enterprise group membership. Knowledge For Market Use 2018, Olomouc.

International conferences

Ac. year	Conference	Citation
2017/2018	GE Grid Solutions User Conference 2017, Brisbane	**Pinos J.** (2017) Implementing Web Map Service into Smallworld GIS Systems, GE Grid Solutions User Conference 2017, Brisbane.

Project work overview

Over the course of study, the author was a member of the following projects at the Department of Geoinformatics:

- Participant in a project of the Internal Grant Agency of Palacky University Olomouc (Grant No.: IGA_PrF_2018_028).
- Project lead and participant in a project of the Internal Grant Agency of Palacky University Olomouc (Grant No.: IGA_PrF_2019_014).

Ing. Jan PIŇOS

VYUŽITÍ BUDOVATELSKÝCH HER PRO ÚČELY PROSTOROVÉHO PLÁNOVÁNÍ
THE APPLICATION OF CITY-BUILDING GAMES IN SPATIAL PLANNING

Určeno pro studenty, partnerská akademická pracoviště a odbornou veřejnost.

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