Univerza *v Ljubljani*
Fakulteta *za gradbeništvo in geodezijo*

VERONICA LORENA ANDRADE SIERRA

SIMULATION OF VISITOR FLOWS MANAGEMENT IN THE SLOVENIAN COASTAL ZONE USING THE TECHNOLOGY OF THE URBAN DIGITAL TWIN

MASTER THESIS

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SIMULATION OF VISITOR FLOWS MANAGEMENT IN THE SLOVENIAN COASTAL ZONE USING THE TECHNOLOGY OF THE URBAN DIGITAL TWIN

SIMULACIJA UPRAVLJANJA TOKA OBISKOVALCEV V OBALNEM PASU SLOVENIJE S TEHNOLOGIJO URBANEGA DIGITALNEGA DVOJČKA

BIM A+ European Master in Building Information Modelling

Master thesis No.:

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Assist. Prof. Tomo Cerovšek, Ph.D.

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Mentor: **doc. dr. Gregor Čok**

Somentor: **doc. dr. Tomo Cerovšek**

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Izvleček:

Mesta so kompleksni sistemi, ki zahtevajo učinkovito upravljanje s podatki glede dnevnih informacij o turističnih tokovih in drugih elementih prostorske mobilnosti. V tem okviru obstajajo številne strokovne diskusije, ki naslavljajo potrebo po nadgradnji konvencionalnega sitema prostorskega načrtovanja v luči aktualnih izzivov sodobne družbe. Tehnološke inovacije in pristopi, kot je Urban Digital Twins, predstavljajo novodobna orodja, ki omogočajo podrobno analizo in vizualizacijo pretoka obiskovalcev po različnih scenarijih. Z raziskavo želimo ugotoviti uporabnost takšnega inovativnega pristopa v procesu prostorskega načrtovanja. Tokove razumemo kot kompleksen sistem interakcij, ki se odvijajo po določenih poteh v urbanem okolju in so odvisni od mobilnosti turizma in zmogljivosti obstoječe infrastrukture. Ta tehnologija nam hkrati omogoča prepoznavanje vedenjskih vzorcev posameznih deležnikov in anliziranje prostorske konfiguracije obalnega območja. Tako nam pomaga pri načrtovanju ukrepov za preprečevanje konflktov, ki se pojavijo kot posledica prenatrpanosti obale. Teoretični in simulacijski pristop z integracijo vzorcev obnašanja obiskovalcev se uporablja za prikaz dinamičnih lastnosti v obliki digitalnega dvojčka. Konkretna študija primera je bila izvedena v posameznih conah slovenskega obalnega pasu. Izdelana je bila simulacija tokov obiskovalcev in kratkoročne mobilnosti, ki jo določajo tokovi pešcev in tokovi cestnega prometa. Ta pristop ustvarja okvir za urbanistične načrtovalce in ostale interesne skupine v smeri boljšega razumevanja ter uporabe sodobnih tehnoloških orodij pri optimizaciji načrtovanja urbanega okolja.

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BIBLIOGRAPHIC– DOKUMENTALISTIC INFORMATION AND ABSTRACT

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Abstract:

Cities are complex systems that require efficient data management in terms of daily information on tourist flows and other elements of spatial mobility. In this context, many professional discussions address the need to improve the conventional spatial planning system in light of the current challenges of a new society. Technological innovations and approaches such as Urban Digital Twins represent useful tools that allow detailed analysis and visualization of visitor flow in different scenarios. With this research, the aim is to find out the applicability of such an innovative approach in the process of spatial planning. Understand visitor flows as a complex system of interactions that take place along specific paths in the urban environment and depend on the mobility of tourism and the capacity of existing infrastructure. At the same time, this technology allows for the identification of the behavioral patterns of individual agents with the spatial configuration of the coastal area. In this way, it is possible to plan measures to avoid conflicts caused by coastal overcrowding. A theoretical and simulation approach that integrates visitor behavior patterns is used to represent the dynamic characteristics of digital twins. The concrete case study was conducted in individual zones of the Slovenian coastal zone. A simulation of visitor flows and short-term mobility, determined by pedestrian flows and road traffic flows, was created. This approach creates a framework for urban planners and other interest groups in the direction of a better understanding and use of new technological tools in optimizing urban spatial planning.

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ACRONYMS AND ABBREVIATIONS:

CIM	City Information Modeling
UDT	Urban Digital Twins
BIM	Building Information Modeling
GIS	Geographical Information System
IFC	Industry Foundation Class
GML	Generalized Markup Language
IoT	Internet of Things
VR	Virtual Reality
AR	Augmented Reality
AI	Artificial Intelligence
ABM	Agent Based Model
GPS	Global Positioning System
PCC	Physical Carrying Capacity
RCC	Real Carrying Capacity
ECC	Effective Carrying Capacity
SHP	Shapefile
WGS	World Geodetic System

1 INTRODUCTION:

In the last decades, most of the studies of visitor mobility are largely based on surveys, physical observation, and guesswork using past research experiences. These resources can be difficult to obtain when it is not possible to contrast the results with official spatial data about the specific zones in cities (Duarte, 2021). Theoretical definitions of a visitors flow about different kind of trajectories such as flows in overcrowding situations can help urban planners understand the behavior of visitors and their relationships in specific time and space. Especially in a tourist environment, where crowd flows or pedestrians and vehicles create a complex and dynamic urban system. Based on flow simulations, tourist destinations can be adequately prepared for periods of an increased number of visits. The importance of redirecting visitor flows to less congested areas and ensuring a positive impact of tourism and balanced sustainable use of the space and economic development is necessary for the correct management of the urban space.

Based on the understanding of cities as complex systems (Batty, 2009) with a temporal process of change (Ulysses, 2017), where several interactions are determined and influenced by specific urban morphologies. These systems create the necessity for a modeling-based complexity approach to the urban systems (Bretagnolle et al., 2006); for example, complex scenarios such as the tourism system (Baggio, 2008). Under those circumstances, the tourism system requires the optimization of scenic spots (Chen & Tang, 2011), and travel trajectories (Park et al., 2021) under the analysis of visitor behavior (Prevoteau et al., 2022).

Cities' understanding of complex systems demands accurate management of their data information. In this way, the importance of City Information Modeling (CIM) as a new technological tool has been highly suggested and recently dressed to fit urban demands (Dantas et al., 2019). The site's context requires a detailed analysis and visualization of the urban spatial data model. Also, data integration and data visualization can be implemented in the whole life cycle of cities (Xu et al., 2021). Giving as a result simulation platforms for urban planning and design.

Because of the urban complexity, the demands for new technological tools with the integration capacity of data management and visualization for the whole project phases are crucial for integrated urban development. Under those circumstances, the importance of computer modeling and simulation of urban complexity systems needs to incorporate human behavior patterns. In this way, the use of the technological tool calls Urban Digital Twins (UDT) (Batty, 2018; Shahat et al., 2021); provides a methodical study of urban dynamics between components, agents, elements, or actors. Considering their interactions in different spatial scales for a detail urban modeling and effective programming, planning, management, operations, maintenance, and sustainability of the city.

The dynamic properties of cities create multiple themes for UDT. The combination between the built environment and social systems creates a necessity to coordinate and link these points. The physical dimension in UDT contains people and their interactions in a specific virtual space. Creating the necessity of the representation of the physical dimension with the social dimension together in a digital accurate virtual model.

Theoretical foundations of complex dynamics based on visitor flows simulations can help urban planners make sense of the behavior of agents and their activities in space and time. Especially in a tourism environment, where crowd flows or pedestrians and vehicles create complex and dynamic systems influenced by the behavior of agents. The main question is if the implementation of new urban technologies as digital twins in over-crowd scenarios in open areas can facilitate spatial planning to improve the analysis of visitor flows. Under those circumstances, simulations about specific touristic destinations will elaborate based on spatial constraints and limitations that produce overcrowding problems in open areas of cities.

The dynamic characteristics of coastal areas offer the possibility to use the technology of UDT. Even more, when the scarceness of data available about fundamental aspects of tourism at a regional level demands more detailed data analysis. The work aims to develop a digital model for the simulation of visitor flows in selected areas in the Slovenian coastal zone. It aims to determine the usefulness of such an innovative tool approach in the process of spatial planning. Focused on the simulation based on tourism crowding creating real-time scenarios. The framework aims to help urban planners have a better understanding of the spatiotemporal patterns for visitor flow and behavior analysis. Additionally, the methodology could be also adaptable to another morphologically diverse environment to prevent over-tourism

1.1 Problem Statement

Coastal zones include recreation, conservation, and population habits which creates a spatial phenomenon of overcrowding flows at multiple levels (Peeters et al., 2018). Several destinations are suffering from a rapidly increasing number of visitors, and the pressure from the tourist industry and its negative consequences influence the development of the coastal zones (Zahedi, 2008). Therefore, it is necessary to establish innovative types of data collection of visitor flows and tourism dynamics.

Limited space constraints on the Slovenian coast include the ecological affection for the marine environment and the physical limited shape of the coast. Due to its environment and touristic attractiveness, public and private interests have been influenced by the spatial development of the coastal zone. Additionally, the Slovenian coast's limited dimensions and at the same time great economic, cultural, and ecological potential, create pressure on the coast area. Tourism development sprawls outside the city center areas creating needs for new infrastructure beyond the carrying capacity of the coast and the road network. Additionally, it is in sensitive coastal landscapes where tourism is making pressure on the natural environment.

Given the very limited spatial possibilities for interventions, from a large number of interests and the conditions for the protection and conservation of natural ecosystems and cultural heritage. Under those circumstances, it is necessary to use new technologies which allow accurate and constant new data collection to be able to evaluate the existing situation of the coast. Space dominated by tourist and recreational infrastructure projects is an important influence on the urban development of the Slovenian coast. New interventions in space must be carefully planned and justified because they will influence the future situation of the coastal area.

1.2 Objectives

Describes and defines a simulation model of road traffic and pedestrian flows on specific zones of the coastline of Slovenia. Flows are understood as a complex system of interactions by viewing traveling along specific routes determined by infrastructure capacity to identify flow behavior as a dynamic approach for avoiding overcrowding on the coast.

Understanding theoretical foundations of visitor flows based into spatial movement patterns under agent-based simulation for the analysis of the actual spatial situation of the Slovenian coast. As a result, identify the crucial zones where overcrowding is happening for future planning and possible regulations about the necessity of new zones for infrastructure facilities and the redistribution of road traffic and pedestrian flows.

Better understand the complex of road traffic and pedestrian flows, and their behavior in a spatial-time perspective. Using system dynamics by simulation modeling of short-term behavior of crowd’s flows, and their influence on the coastline space to reduce them. Finally, verify the implementation of this new urban digital technology in the field of spatial planning

1.3 Methodology

This research starts with the understanding of two main concepts: City Information Modelling and Urban Digital Twin concerning the use of modeling simulations for planning and predictions of urban scenarios. Then, explain the importance of analyzing crowd flows models under human behavior determining pedestrian and road-traffic behavior definitions in simulations models. Consequently, a detailed review of a specific software tool technology (Any-Logic) and its main connection with the Geographical Information System (GIS) is used in this research to provide an example of simulations with characteristic detail of Urban Digital Twin (UDT) simulations.

Additionally, a spatial configuration analysis of coastal zones about over-tourism and mobility is considered. After these main concepts analysis, a specific case study is determined using the Slovenian coastal zone. Then, a deep investigation of the main spatial characteristics of the Slovenian coast is set concerning topics such as infrastructure, tourism, and visitor flows. Finally, simulations are placed in different scenarios in the environment of determined areas in the coastal zone of Slovenia. Using the software (Any-Logic) to demonstrate the use of model simulations as one type of tool technology for the Urban Digital Twin application.

Two sub- questions are established for the detail develop parameters of the simulation's scenarios:

- What happens if the inadequate use of the coast increases? Simulate what-if scenarios.
    - Relation between available surface and occupation level
    - Analyze visitor flows to main routes determined by trajectories in space and time.
    - Predicting paths that cars or pedestrians might take to move from one point to another
    - Develop an observable travel behavior that explains according to trajectories relevant interactions with supply elements (main nodes)
- How do the actual characteristics of the coastline in Slovenia space influence and constrain tourist and local flow behavior?
    - Define traveler types and segments
    - Establish main points according to travel needs and travel preferences according to scenic spots or facilities placed as main nodes in the route.
    - Modeling the short-term pedestrian and traffic flows behavior to determine overcrowded periods.

2 CITY INFORMATION MODELING AND URBAN DIGITAL TWINS

2.1 City Information Modeling (CIM)

Cities demand new technologies to arrange their needs of design, planning, construction, and maintenance. CIM is a process and computation-based knowledge that involves systemized data, attributes, and parameter association of city systems. Facilitates visualization, analysis, monitoring, and simulation of the urban environment. CIM is considered a multidisciplinary unification of all spatial data models, in conceptual terms, collaborative work, and interoperability (Dantas et al., 2019). CIM is essential for the integration of city data to assess and guide the performance management of city services (Table 1).

CIM research areas	Data collection
	Integration
	Visualization

Table 1: CIM research areas. From (Dantas et al., 2019) (Own resource)

Topics such as energy, environment, recreation, risk, safety, innovation, transportation, water sanitation, and urban planning are crucial information databases for CIM models. This data can be acquired using different resources such as computerized mapping allowing the observation in real time of cities´ behavior and their development with accuracy. This technological tool can help to monitor these several topics of urban development in specific cities and towns in smaller intervals of time according to their planning purposes and necessities.

CIM can incorporate BIM models attached to GIS georeferenced representations into the CIM which is compatible with the industry foundation class IFC as a standard data format. Additionally, compatible with the markup language City- Generalized Markup Language GML as a common format for GIS data (Xu et al., 2021). Also, virtual reality (VR), augmented reality (AR), the Internet of Things (IoT), big data, cloud computing, machine learning, and artificial intelligence (AI) have become part of CIM (Figure 1). This resource helps to recreate and build smart cities with an accurate digital representation in real-time named Urban Digital Twin. This tool generates a complete model of information about cities' performance of public services and infrastructure allowing taking more efficient decisions for spatial development.

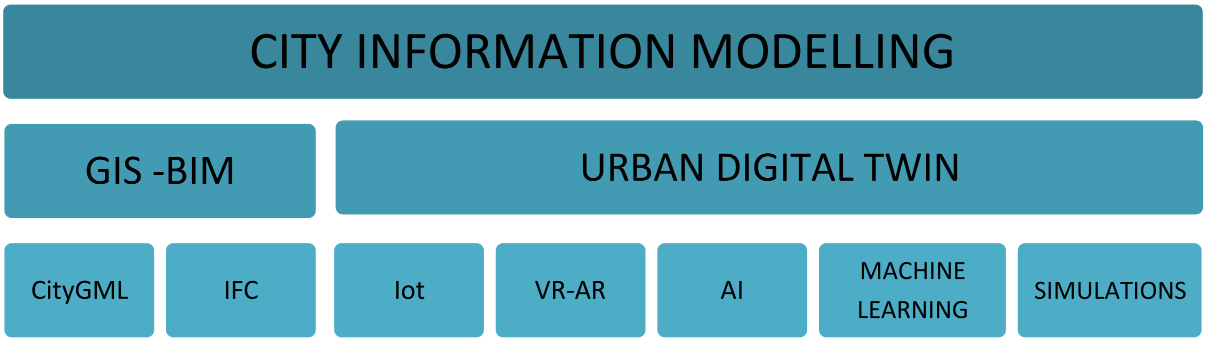

Figure 1: CIM components

2.2 Digital Twins

The main terminology of a digital twin refers to a digital representation of an element or process with different data connections and exchanges which allows not just visualization, but also a representation of the agent's behavior in the real world. Digital twins establish synchronization between the physical and digital states with the capabilities of data exchange, integration, analysis, simulation, visualization, and optimization. Additionally, it is a digital representation of different physical entities and processes, systems, people, places, and devices, and is used not only in the field of urban analytics but also in the computational social sciences domain (Charitonidou, 2022). Digital Twin is not an exact copy. But aims to become an identical representation to its physical counterpart. Using real-time data concerning all accurate information about the system or object represented. Generating real-time connections between the virtual and real space. Also, using the specific data obtained for the improvement of short and longer (what if) scenarios. As a result, digital twins can be defined as digital tools that contain models, data, and simulations. This data may relate to the lifecycle of the system.

The main advantages of the use of Digital Twins include (Table 2):

Digital Twins Advantages	Increase operational efficiency
	Resources optimizations
	Improved decision making
	Cost savings
	Real-time monitoring

Table 2: Digital Twin's Advantages. From: (Charitonidou, 2022), (Own resource)

Digital Twin is a virtual model representation. This model aims to be a similar representation of a physical world determined using real-time data to be able to anticipate a problem before it occurs. Digital twins produce data intensive. Thus, data is required for their simulation and synchronization with the "real" world (Xu et al., 2021). A digital twin can connect past and present information for future scenarios.

The main challenges Digital Twins confronts are (Table 3):

Digital Twins Challenges	
	Data accurate and quality
	Interoperability
	Open standards
	Visualization integration
	Representation of large size model
	Citizen´s privacy and data security issues

Table 3: Digital Twin's Challenges. From (Xu et al., 2021) (Own resource)

2.3 Urban Digital Twins (UDT)

The use of digital twins at the urban scale, Urban Digital Twin combines dynamic data obtained from several resources such as sensors and geospatial technologies which allows the development of urban dynamic properties of the model to be represented. UDT combines several processes and systems. Emphasize the use of data, such as algorithms, machine learning and data analytics. In this way, simulations can be updated according to the space characteristics in real-time as their physical equivalents change (Ribeiro, 2021). UDT is based on geospatial information, city models, sensor webs, technology frameworks, data science, cameras, and crowdsensing, among others. In this way, several models will need to be applied, including physics-based models or functional models (Xu et al., 2021). The dynamic properties of cities create multiple themes for urban digital twins. The combination between the built environment and social systems (beliefs, goals, objectives, roles, and feelings among others) creates a necessity to coordinate and link these points (Figure 2). Finally, these interactions demand the necessity of the representation of physical and social dimensions in an accurate virtual model synchronized with real-data information.

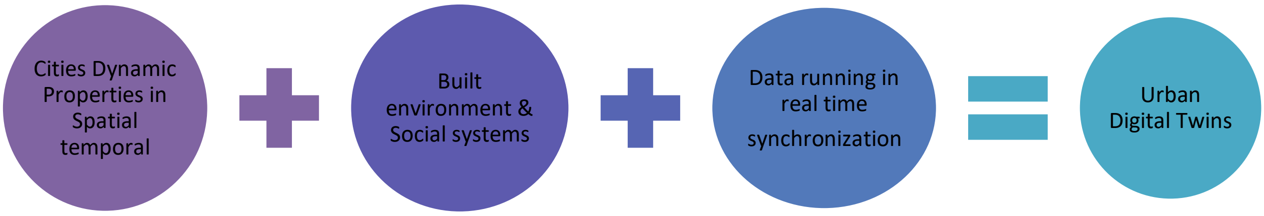

Figure 2: Digital accurate virtual model synchronization

It is important to focus that cities are not automated systems that can be easily understood and predicted (Shahat et al., 2021). Also, (Batty, 2018) argues that: any system that can mirror the operation of another different system is commonly defined as a model. This implies the model is a representation of the structure and processes. This representation defines the system to which it is being established or compared. Models are simplifications of the real system represented so this means, the model does not search to replicate the original system in the same detail as the main system. Nevertheless, the existing model's representations are close to the real system which is the main definition and purpose of the digital twin to be a complete mirror image of the real system represented (Figure 3). The crucial point of the digital twin characteristics is the data running in real-time which is equal to the whole system. The difficulty of managing information in constant actualization for a whole system is because on a city scale it becomes difficult to manage and process huge quantity data.

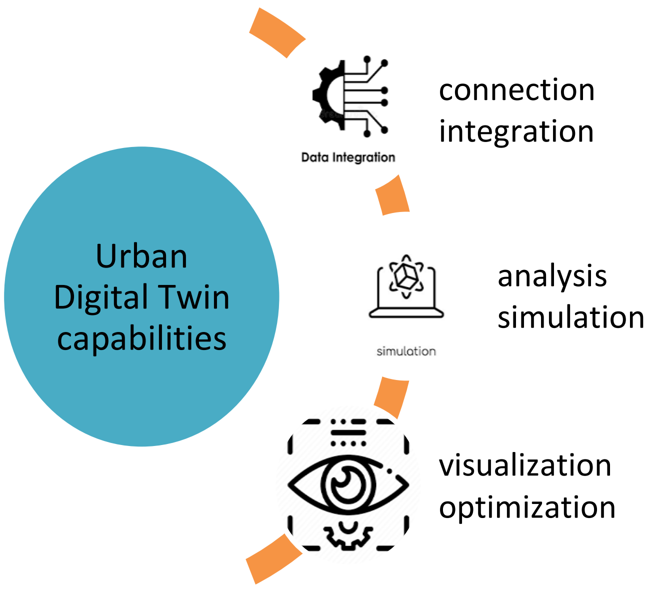

Figure 3: Urban Digital Twin capabilities

Cities have the necessity to digitize their systems which have transformed resources about how to obtain and process data from cities. According to (Blair, 2021): It is important to model systems to get a better capture of complexity. This complexity should be concerned about including interactions, coupling, feedback, and several dynamics in the system. For instance, (Xu et al., 2021) argue that spatial data allows micro, medium, and macro relationships necessary to be established, aggregated, analyzed, and simulated. Parameters such as space, and time are part of a system of systems approach necessary for understanding and optimizing the urban environment. In this way, Geographical Information Systems (GIS) provides the context of several digital physical representations to evaluate all the physical assets in the city. The combination between space and time is part of the digital twin system approach established to synchronize the urban environment. A key value of UDT is shown that a place that is based on urban planning and design is transforming an important aspect of city renewal intervention projects with a digital model closer to the real system (Figure 4). City modeling refers to re-create the integration of the systems which conform to the city scenario such as physical, natural, and social elements.

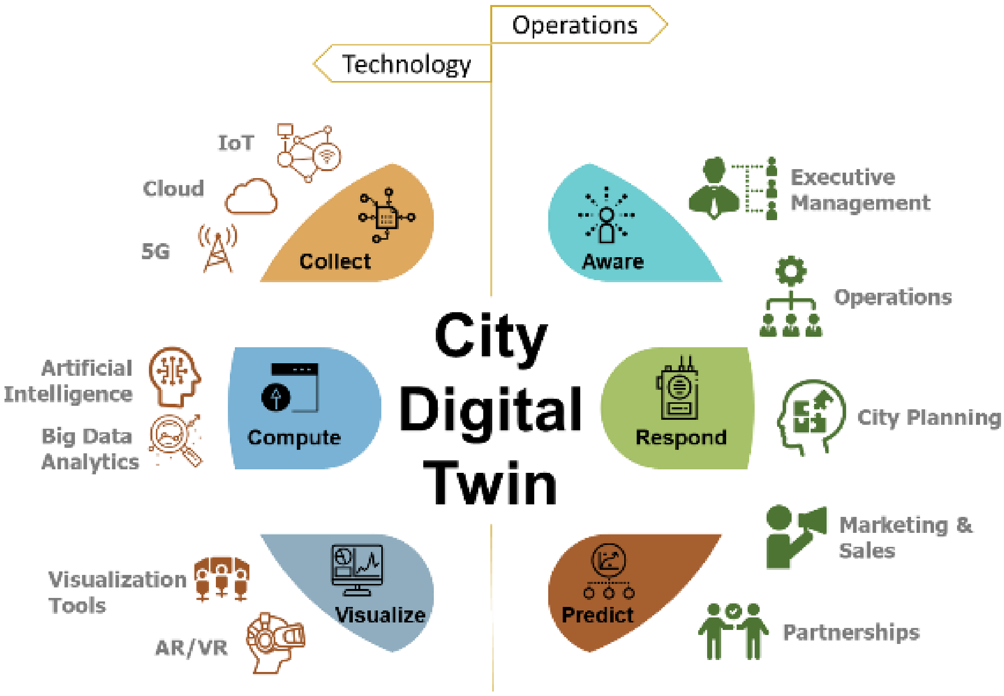

Figure 4: City Digital Twins: Benefits and Technology Enablers. From: (Huawei Technologies Co., Ltd., 2022)

2.4 Simulations for Planning and Prediction

Simulations use and produce data of models (characteristics or behaviors of selected systems) in evolution over time allowing to have detail visualizations (representation of data) in specific scenarios (spatial time) giving as a result data which can be used to predict future updates and anticipate a problem before it occurs (Figure 5). Simulations can develop scenarios based on actual situations or predict (What

If?) future scenarios. Additionally, simulations can determine specific patterns and plans for new urban development strategies. Providing a collaborative environment using the integration of information from main elements such as technologies, humans, environment, and infrastructure within the complex scenario of the city.

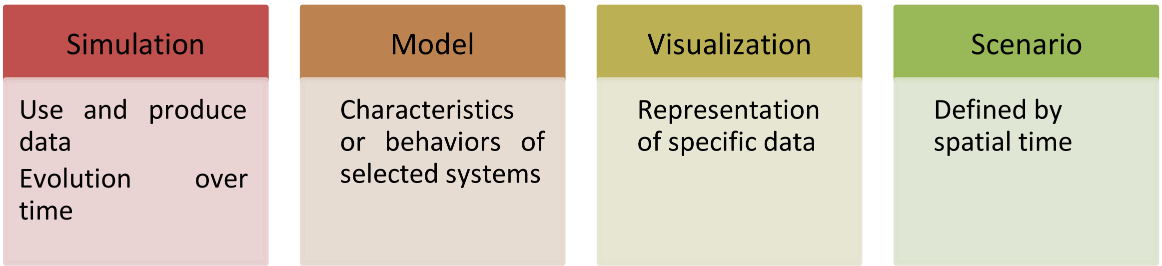

Figure 5: Definition of main words used in simulation environments

Simulation models can replicate scenarios for planning and decision support. Simulations are useful resources with a risk-free, and low cost. Additionally, simulations allow for the creation of virtual environments where it is possible to test different scenarios in short- or long-term time. In the same way, it provides new compare alternatives to the environment where modelers can interpret the best design parameters.

Several methods and software are used for building simulations for UDT. Under those circumstances, standardization and open standards should be applied to facilitate data management and interoperability between them. More simulation software is appearing in the market with the approach of developing a complete and comprehensive virtual model considering the different city´s functions and processes. These functions and processes are developed within the spatial-temporal dimension which can include models representing short periods such as seconds, minutes, hours, weeks, or months. Or long periods such as years, decades, or even centuries. Simulations that allow the real, near, or longer time scenarios for an asset, to evaluate and predict accurate decisions in the design and planning of the cities.

2.5 Crowd Flow Simulation Models

The visualization of cities is complex because of all the different process model details required for the full representation of the city in the digital model. Searching accurately behaviors and dynamics systems under observation. Generating the visualization of non-physical systems such as social preferences, emotions or interactions is a complex action and significant challenge (Shahat et al., 2021). For instance, simulations of crowd situations in specific spaces allow ensuring different aspects such as safety, comfort, and efficient process. These simulations can be determined by the origin-destination data influenced by specific measures such as visibility, shortest or quickest routes, and connectivity parameters, among others.

Also, an important point to consider is the simulation speed which becomes a more challenging issue when demand arrival patterns or origin-destination matrices are influenced by the needs of people in a move from one point to another. Crowd simulations are typically designed for commuter populations but being able to extract data about peak users and so on will allow the development of more accurate realism to the simulation. (ARUP, 2019). The city crowd size information is relevant for appropriate crowds to manage purposes in urban planning. Nevertheless, data information about the crowd in specific urban areas is not easy for several factors such as restrictions on the use of cameras or drones in some public spaces. Commonly, crowd size estimations, and surveys have several human errors. The process to collect data from tools such as drones, cameras, sensors, or counting systems can be difficult to implement because of their expensive cost, especially for large amounts of city events when many technological tools such as drones, sensors, or cameras are needed (Gong et al., 2021). Nevertheless, several techniques can be developed such as image counting analysis, crowd scenarios with methods such as algorithms, machine learning, statistical analysis, or an inclusive social media dataset of images. As a result, an accuracy model about crowds creates the necessity to develop new methods with the information available for accurate density estimation-based approaches.

2.6 Aged Based Simulations

Agent-based modeling interacts with multiple entities known as multi-agent or individual-based modeling. Agent-based modeling is considered computational modeling of a real-life system compound by autonomous entities. Agents are characterized by each behavior and decision taken based on rules and defined variables, establishing interactions and adaptability to the modeled environment. An agent has a set of possible actions, different rules of behavior, and variables that set its internal state (Figure 6). These dynamics state spatial-temporal analysis of real-time updating flow by using dynamic interactions modeling agent behaviors.

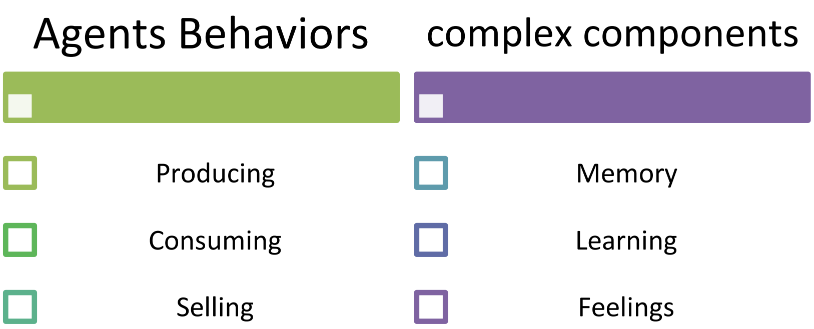

Figure 6: Agent behaviors and complex components

Agents in an agent-based model can be represented by different things such as people in different roles, equipment vehicles, non-material things (products, projects, ideas), and organizations (countries, companies, among others). Agent-Based Models (ABM) have been applied successfully in modeling short-term behaviors of overcrowding situations with people as part of social science theory. Agent-based models have been applied in a hypothetical situation or closely constrained by real-world scenarios, and situations (Ward et al., 2016). This kind of simulation focuses on the agent mobility patterns; the main approach is understanding the system dynamic influenced by the behavior of the agents within a specific environment. Agent-based models give useful information about the interaction of different agents including parameters such as densities with the function of time (Shrikant B Sharma y Vincent Tabak, 2008). This environment produces specific flows determined by the movements and relationships between agents, in real-time modeling. Each agent represents an autonomous entity that acts based on input data rules established at the beginning of each simulation (Figure 7). To sum up, Agent-Based Models are tied with the concept of Digital twins where entity information is fed dynamic real data allowing representation into simulations in different scenarios.

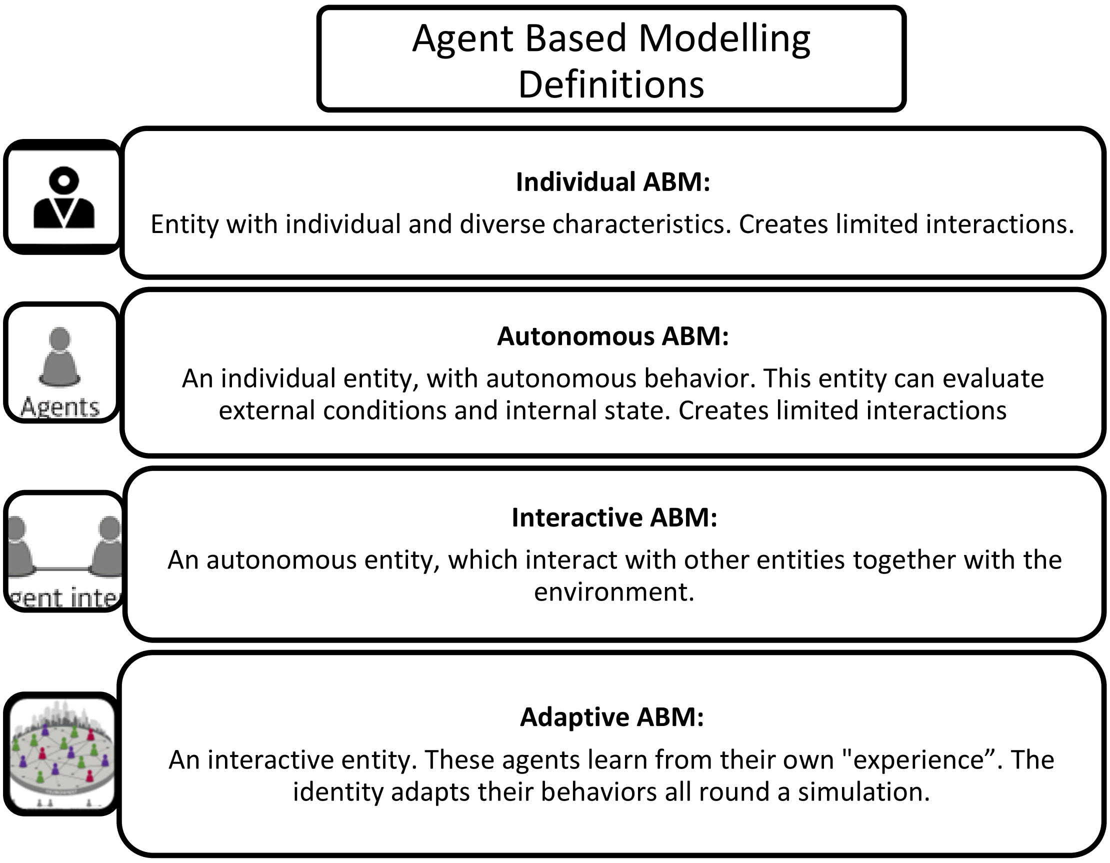

Figure 7: Agent-Based Modeling definitions. From: (Shrikant B Sharma y Vincent Tabak, 2008) (Own resource)

2.6.1 Pedestrian Behavior Flows

Pedestrian behavior patterns can include interactions, correlations, rules, and causality between the occurring behaviors and the environment (Banaee, 2021). People flow simulations of crowd-flow scenarios are complex, creating multi-directional flows influenced by different behavioral parameters which imply a random probability distribution. For instance: people's mobility models tend to be complex because these flows need to consider several combinations of different factors. These factors can be agent interaction, spatial configuration, and population behavior (Shrikant B Sharma y Vincent Tabak, 2008). Dynamic human emotion and behavior can be divided into regular movements which depend on their routines and irregular movements which depend on the probabilities.

Additionally, the attractiveness of specific locations can have an important impact on the agent's behavior determining the frequency, and the average number of visits. Models can represent a single pedestrian or group of pedestrians with their own rules of behavior. Different groups can move through the network compound by nodes and links. These flows reveal the spatial interaction between specific nodes influenced by the level of attractiveness of useful resources, especially for tourist flow. Touristic hotspot analysis helps to understand how tourists behave and what tourists like or dislike (Bernd et al, 2020). The analysis of interactive networks based on visitor flows can be helpful to express the spatial agglomeration and diffusion phenomena of visitors, and analyzing roles, functions, and interactions in the main spatial nodes (Tian et al., 2022). These nodes show the sites which are an important part of the visitor flows. These nodes must be seen according to their main roles within the whole trip way, just not always only at the place of the trip. It is important to realize that every place on a specified route has something special that takes the attraction of visitors and makes them stop at specific sites during some period. Making this specific site important for at least one segment of visitors (Flognfeldt jr., 2005). As a result, the dynamic human motion represented by pedestrian flows can determine specific points in the urban space influenced by the level of their attractiveness, giving determining hot spots considered relevant for the analysis of visitor flows.

Trajectory networks generate corridors to connect the tourist nodes where attractions and activities belong together. Consciously way or not, visitors move in several ways as they move to the destination site. In the meanwhile, visitors continuously generate moments of interaction and a variety of experiences. (Beritelli et al., 2020). Each of these flows created by spatial and mental directions is crucial to understand to represent an accurate conceptualized travel in their virtual representation (Figure 8). Despite this, visitor flow behavior data from initial movement until at a destination level is difficult because represents a social complex phenomenon that is neither available data detail information nor easy to collect.

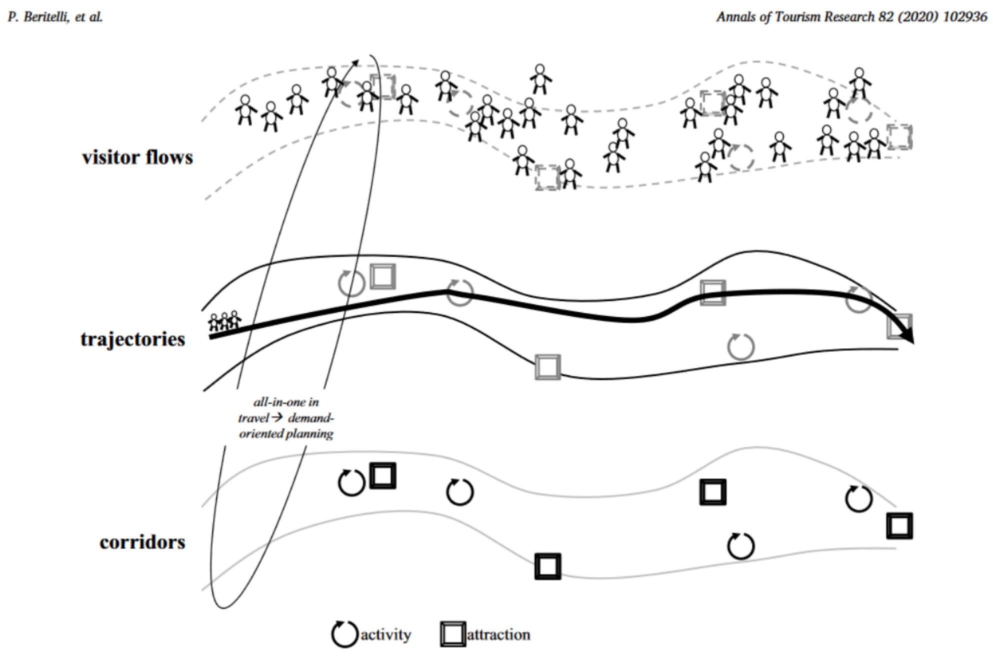

Figure 8: Visitor flows, trajectories, and corridors. From: (Beritelli et al., 2020)

The collective performance of flows is defined by the density, and frequency, of the urban environment in spatial-temporal (geo-time-tagged) data information. Simulations as elements of the Urban Digital Twins are dealing with the integration of accurate data from social behavior captured as an important feature of the visitor flow concept. Although according to (Beritelli et al., 2020), technologies-based instruments are used to collect and process visitor flows data. Additionally, algorithmic methods are used to understand visitor data. This data still cannot fully, explain, find, and predict the factors which affect the drivers of visitor behaviors, and the reason is that visitors move to places and dislike certain elements. In the meantime, simulations as a manifest of travel reality allow representing visitor flows as a collective experience that is simultaneously or sequentially executed by similar trajectories. Visitor flows can be analyzed by video cameras, mobile phone tracking data, and counters sensors, giving detailed data information about the travel destination's reality. Finally, this information will be necessary for revealing interconnection between zones in terms of mobility to avoid overcrowding visitor flows.

2.6.2 Road-Traffic Behavior Flows

Transport and movements, routes, and destination areas are topics examined by several geographers as essential trajectories for understanding the movement of agents. Transit routes are paths linking visitor flows, their characteristics of routes influence the quantity and quality of different access to destinations. Also, the routes influence the direction and the size of human flows (Flognfeldt jr., 2005). Thus, transit routes are paths linking tourist attractions. The specific characteristics influence the quality of each destination, generating and influencing the size and direction of flow development.

New technologies such as sensors, on-site monitoring via Global Positioning System (GPS), video recognition, digital panels, and mobile phone positioning among others can be used continuously throughout the year. These are useful tools for capturing movement data in real time. These technologies relate the movement data with spatial and temporal details. Using car counting as a monitoring tool is a useful method because it can produce information about the average number of vehicles giving the possibility to estimate the number of visitors throughout the year. Under those circumstances, flow data analysis methods have been used in several types of tests about transportation (Figure 9). As a result, real-time and future traffic data for vehicle traffic developers can be obtained.

Additionally, it is possible to obtain information support for the relief of traffic jams. Traffic flow is related to distances, volume, occupancy, and speed in correlation with time and space. Traffic flow is directly influenced by the structure of the road network explaining the deeper behavior of traffic patterns. In the simulations, the environment can be the road network in the city. Indicators such as occupation level, and most visited sites can determine the direction of road traffic flow generating valuable data for establishing the optimal routes and city road traffic management.

In the case of road traffic behavior flows, it is necessary to understand the movement pattern by trajectory data based on movement patterns. These patterns from road traffic provide valuable information and generate specific sequences that can be modeled in a simulation combining different types of nodes. For instance, parking lots, restaurants, touristic places, and cultural sites (Bing et al., 2020). These models establish a trajectory-based method where the spatial dimensions can be analyzed. In the tourism environment system, transportation is determined by destinations, attractions, and settlements. In this way, simulations can be executed under a representation of visitor flow patterns. This analytical tool helps to facilitate the delineation of areas with crowd tourist impact.

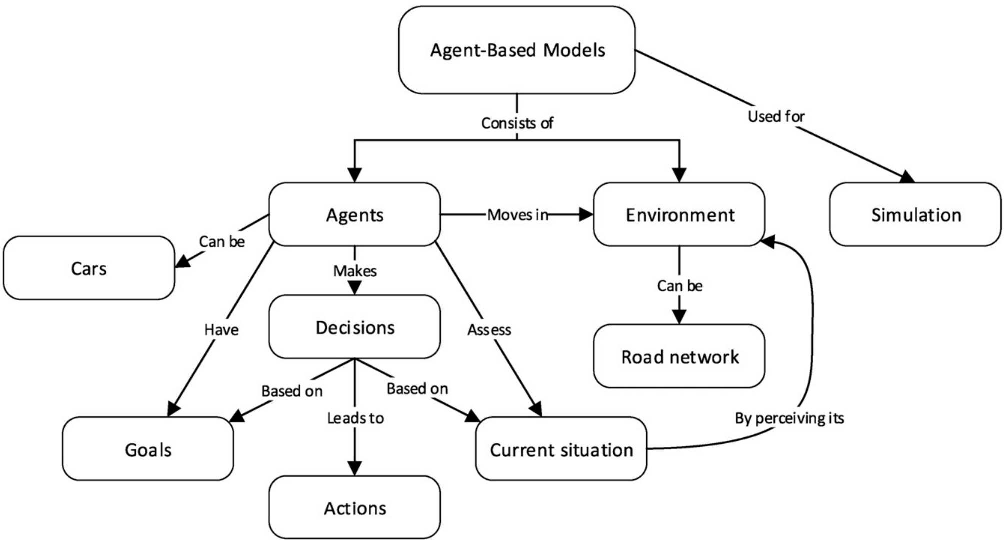

Figure 9: Agent-Based Model environment. From: (Hall & Virrantaus, 2016)

3 VISITOR FLOWS INFLUENCE ON COASTAL ZONES

3.1 Spatial conflicts in coastal areas

Several consequences can occur if touristic places do not consider the carrying capacity. Wrong tourism development can severely affect the urban and natural space in cities. Estimation of the conflict intensity can be evaluated in spatial conflicts related to the over-concentration of visitors in specific areas such as coastal zones. Additionally, infrastructural conflicts such as heavy traffic concentration, and socio-cultural problems between the resident population and tourists.

Coastal environments attract several numbers of tourists producing several conflicts between the conservation and development of these touristic places. Tourism development in the coastal zones has interchange attractiveness of the destinations producing. These have been influenced by changes over the original configuration of the zone which counted on attracting tourists. (Zahedi, 2008). The spatial configuration and management of the tourist's space will determine the conflicts, coexistence, and symbiosis between the locals and visitors. Monitoring these coexisting movements produces data about the different impacts of tourism affecting the environment. These data are useful to make evaluations of spatial conflicts from a system perspective. Where the components of systems are linked in a network of visitor flows determining specific connections and intensities of the space use.

It should be noted that various protocols deal with the challenges of planning activities in the coastal zone, such as the ICZM protocol (ICZM Protocol, 2008) which provides the legal framework for the appropriate management and use of the Mediterranean coastal zone considering the fragility of coastal ecosystems, activities, uses, and their interactions in on marine and land parts. Additionally, the MSP (Maritime Spatial Planning) (Maritime Spatial Planning in the Mediterranean Sea | MSP MED, 2017) directive which is a spatial planning development document, which provides main guidelines for the principal actions and activities for the different uses in the sea and coastal area. These resources show that the coastal area is a subject of great administrative and professional interest and maritime countries are putting effort into different research about spatial planning and sustainable development of this zone. Giving as a result different challenges related to tourism approaches.

The spatial properties will determine the spatial interaction between people and land creating a spatial planning synergy based on behavioral characteristics. Visitor flows are determined by different trajectories that conduct activities in the coastal environment. These activities are developed in determining space and time. Space and time are important factors that influence and constrain the behavior of visitors within touristic places destinations (Ma et al., 2021) (Figure 10). Different constraint types can determine spatial interaction as distance constraint, shape constraint, pattern constraint, and zone constraint. As a result, these spatial constraint types define visitor mobility behavior. These dynamics determine the specific mobility rhythms of coastal cities with their users.

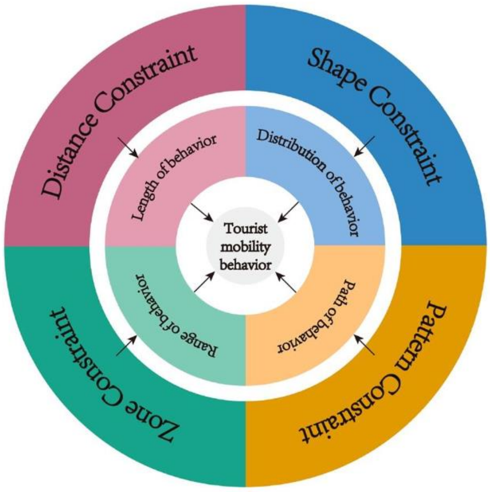

Figure 10: Tourist mobility behavior. From: (Ma et al., 2021)

3.2 Coastal Carrying Capacity – Over tourism

Coastal environments are zones where people define several activities as economic, social, and recreational with a tourism impact. Tourism in coastal zones includes recreation, conservation, and population habits in determining areas which creates a spatial phenomenon of flows and concentration at multiple levels. Several destinations are suffering from a rapidly increasing number of tourists, therefore necessary to establish innovative types of data and visualizations about tourism flow and tourism dynamics. Conservation of natural resources and awareness of the carrying capacity is crucial (CEETO, 2018) for controlling over-tourism in a way that leads to adequate management of flows of tourists and mitigates their negative effects.

According to (Cifuentes, 1992) who determined the touristic carrying capacity in protected areas (Figure 11), a source used widely in several types of research. He established the “carrying capacity as the relation between the occupation level in the available surface, establish by levels of physical carrying capacity (PCC), real carrying capacity (RCC), and the effective or permissible carrying capacity (ECC)” (Huamantinco Cisneros et al., 2016). These parameters can determine the maximum number of people that can stay in a specific area is determined by considering the crowd's worst scenario. Although carrying capacity is considered an imperfect measure, it can be implemented as a reference value for overcrowding scenarios. Based on the theory of Beach Carrying Capacity occupancy developed by Norma Cubana in 1988. This theory establishes three different scenarios for low, medium, and high occupancy in the space. This concept will be useful for establishing crowd scenarios in simulation models in coastal tourism environments.

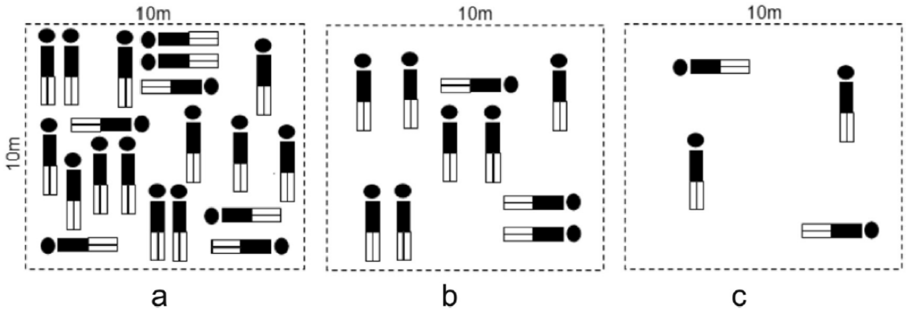

Figure 11: “Occupancy condition criteria (in m2 per occupant): a) 20 people/100 m2, b) 10 people/100 m2 and c) 4 people/100 m2, which corresponds to an area of, 5, 10, and 25 m2 per user, respectively”. From: (Huamantinco Cisneros et al., 2016)

Managing tourism is avoiding depletion or degradation of the environment. Over tourism, manifestation is clear to see in pedestrian or traffic density in visiting places. The specific touristic place gives the limit of occupation according to area capacity, environmental conditions, infrastructure capacity, and connectivity with external places among others. These areas are limited in how many tourists can stay in a specific area or can visit a place simultaneously. Touristic places can experience limited resources. Thus, the tourism facilities, services, and their different levels of service such as infrastructure are also limited, parameters that influence the maintenance of the quality of tourism resources, activities, and the wellbeing of residents. (Duarte, 2021). As previously stated, the number of visitors in a destination area will be determined according to the quality of the tourism capacity.

Tourism is considered a complex system, influenced by the dynamics of interaction between agents and the environment. Developing an accurate tourism model is necessary for real-time monitoring to obtain accurate data about the number of visitors to a specific zone and destination. It is important to understand how pedestrians and vehicles use the urban open space and how they create integrations in a complex system. Therefore, the resource of simulation can help to understand the complex system from a tourism perspective with the approach of preventing crowding.

3.3 Attractiveness and mobility

Attractiveness is a dynamic concept of spatial interdependence influenced by exogenous or endogenous circumstances. Attractiveness is influenced by the quality of infrastructure and accessibility which will determine mobility as the main factor to address. The mobility of residents and visitors has an impact on cohesion. Creating several dynamics of flows and concentrations according to the level of attractiveness of a specific place. These situations without correct planning can produce crowd scenarios affecting the quality of the territorial balance. According to (Russo et al., 2013): Dynamics drive population mobility because population flows are determined mainly by economic forces. Under those circumstances, it is crucial to analyze mobility and attractiveness in a spatial dimension as the main factors of regional development.

Cities and regions can be considered attractive according to the quality of the place. Nevertheless, quality is not an easy element to quantify because several aspects can influence its perception. Attractiveness in a touristic place can be considered a natural phenomenon where considering the types of tourists it is crucial to determine mobility in detail. Different effects can be expected from each of the types of tourists, determining differential outcomes of the attraction processes. Disturbances for the local community and environmental pressure can affect the territory. Therefore, a balanced relationship between the attractiveness of places for residents and visitors should be considered as strategies of mobilization where social and environmental ecosystem cohesion should also be an important consideration objective. Finally, territorial attractiveness can be understood as a complex interaction between geographical attributes, dynamic processes, and a set of factors. The dynamic process of mobilization flows between residents and visitors.

3.4 Continue monitoring of flows

Continue monitoring of flow demands and manage the information which is updated constantly. Monitoring implies collecting data from a wider perspective such as conservation, number of people using determined services, number of visitors, and community development results. (CEETO, 2018). Parameters that define flows in the structure space necessary to consider are:

- Accessibility
- Distance
- Destination
- Shape
- Pattern
- Zones

These parameters determine the structure network of main points according to their level of attraction or utility called nodes; these are determined by:

- Frequency of visits
- Presence and intensity of the visit
- Permanence
- Repeatability
- Territorial preferences

Additionally, the connections between these nodes are executed by links as:

- Road network
- Cycle network
- Walking network

4 CASE STUDY: SLOVENIAN COASTAL ZONE

4.1 Tourism in Slovenia

Tourism in Slovenia is aimed at the principles of sustainable tourism. Slovenia manages the green points of Slovenian Tourism as tool management at the national level. Slovenia offers destinations and service providers that allow them to improve and evaluate their sustainability. (CEETO, 2018). In this context, green tourism means harmonization between different scenarios as economic, educational, socio-cultural, and environmental, crucial aspects for the progress of sustainable tourism.

Slovenia is considered one of the 12 most sustainable destinations in Europe. Nevertheless, it is facing problems in determining sustainability in several scenarios as expressed in (CEETO, 2018): According to the Regional Development Center Koper, Slovenian Tourist Board describes the main approach to sustainable tourism. They search to establish sustainable tourism as the correct development opportunity for Slovenia. Implementing integral management of sustainability in all tourism activities. This is how the range of tourism services offered in the country represents the principal aspect of competitiveness. Several tourist places are dealing with pressure, especially in the summertime. Tourism shall focus on access to the main destinations. Especially the coastal zone which is part of the green system.

4.2 Slovenia Coast Infrastructure

Koper is the economic, administrative, cultural, educational, and employment urban regional center. Thus, it is an important traffic area where connections between shipping, terrestrial transport of cargo, and a developing passenger port create an important influence on the dynamics of the coastal area of Slovenia. The majority part of the Slovenian coastline is urbanized with a dense public infrastructure, the natural coasts are conserved only in places where urban development was limited such as difficult terrains and cliffs. The coastline has been growing in the last decades and is expected to develop further in the future. The maritime economy is generating a big influence in the territory with the ports especially the Port of Koper. Koper represents an entry point at which the EU Baltic-Adriatic corridor links the land and maritime passenger and freight transport; it is also important for the international integration of Slovenia and the economic development of the wider hinterland (Vane Urh et al., 2018). This port search is to be fully connected by transport as the railways, roads, and inland waterways because of the important economic and regional influence on the country.

According to (Vane Urh et al., 2018) since 2011, the Port of Koper has welcomed cruise ships with receiving passengers in the range between 57,000 and 80,000. The Port of Koper does not expect a substantial increase but ports such as Izola and Piran will increase the number of maritime transports within Slovenian waters. Additionally, the area of Izola is pretending to increase the public spaces for touristic purposes (Figure 12) such as bathing waters and water sports.

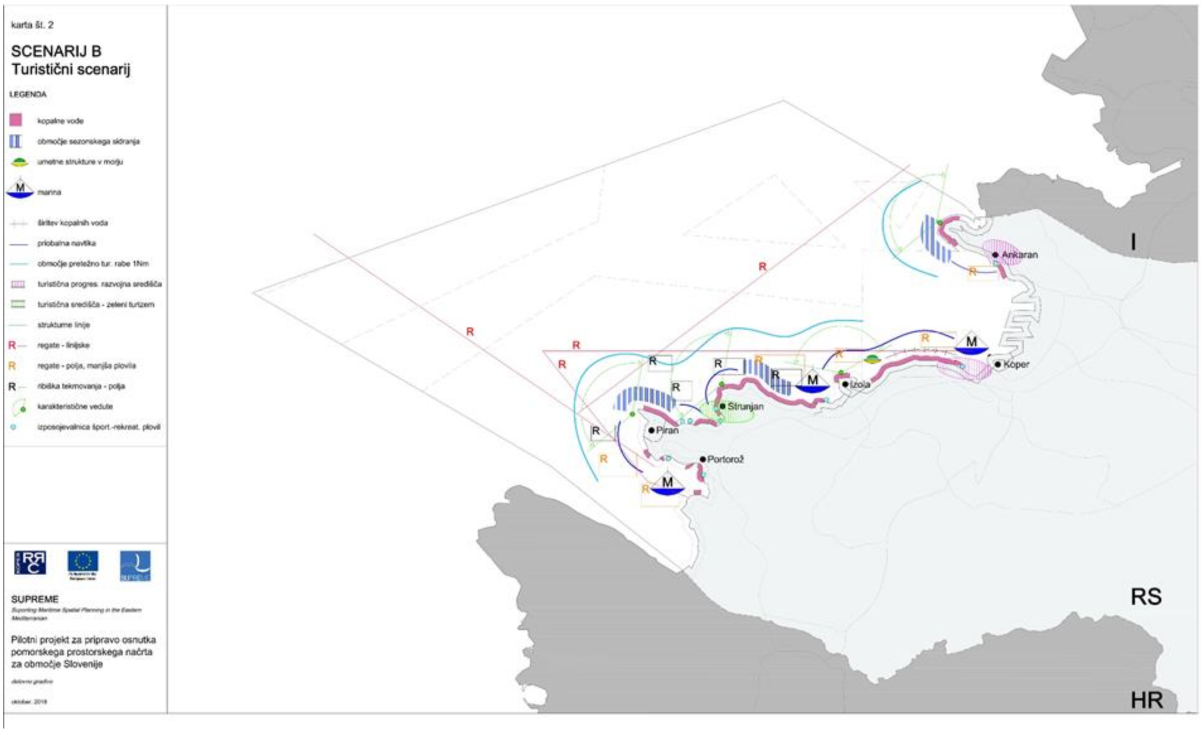

Figure 12: Tourism scenario. From: Čok, G.; Plazar, M. SUPREME: Pilotni projekt za pripravo osnutka Pomorskega Prostorskega Načrta (PPN) za območje Slovenije (Zaključno poročilo); Regional Development Centre Koper: Koper, Slovenia, 2018.)

In 2015, a new express road of 3km long between Koper and Izola was built. This long coastal area aims for sustainable use incorporating leisure activities such as cycling, walking, and skating together with natural protection. This area is also a Natura 2000 site. According to (Vane Urh et al., 2018) In all four coastal municipalities, there are 2,090 registered holiday apartments. In 2016, the coastal municipalities had 8,637 rooms offering 24,938 beds (SURS, 2017c). The SURS (2017d) reported that in 2015 the Coastal-Karst Region noted 736,239 tourist arrivals 43 and 2,268,507 overnight stays. The tourism sector is growing; SURS (2017e) showed that in May 2017 there were 7% more tourist arrivals than in May 2016. However, the tourist demand is highly seasonal and unevenly distributed across the four municipalities. Under those circumstances, the coastal region is supporting crowd-flows of visitors and demanding more services and infrastructure. These show the importance of improving investments in new tourism facilities such as public beaches, sports infrastructure, sustainable mobility solutions, and plans for protected areas.

The three municipalities Koper, Izola, and Piran are focused on creating new infrastructure projects as smart beaches, improving the conservation of natural areas, and becoming tourist destinations with exceptional tourist offers as sports tourism and recreation sites preparing additional beaches and bathing areas without physical barriers (Figure 13). Public spaces seek to be improved achieving the status of bathing waters and water for sports all connected by a sustainable mobility network. Nevertheless, all these goals must be implemented by considering the real carrying capacity of the spaces and analyzing the flows of visitors to establish an adequate number of effects in marine waters and urban spaces.

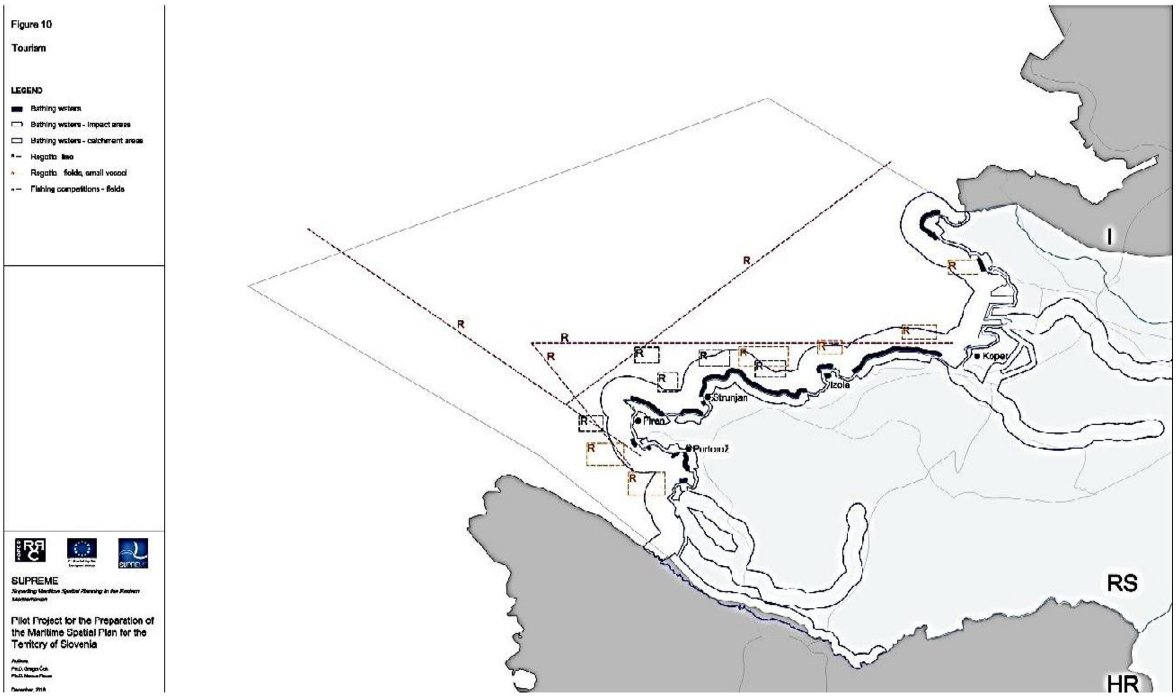

Figure 13: Pilot project of the Maritime Spatial Plan for the territory of Slovenia. From:(Vane Urh et al., 2018)

The last year 2021, Slovenia adopted the Maritime Spatial Plan (Čok, Mlakar, et al., 2021). In this plan, the sea and coastal areas are recognized as important spatial and development advantages for Slovenia, where the natural dynamics of coastal areas are maintained. Slovenia has mainly been considered a maritime-oriented country focused on the preservation of coastal areas as a national and spatial identity.

4.3 Population flows on the coastline of Slovenia

Slovenia occupies a small part of the northern Adriatic coast. The name of the Slovenia Coast became established after the Second World War, including coastal lands and the remote hinterland. The entire coastal area covers about 410 ha area with 46 km long, where spatial analysis indicates pronounced urbanization as 57.8% of the entire coastline (Čok et al., 2021). Urbanization has focused almost exclusively on coastal towns. This place aims to ensure effective access to the sea either from urban areas or from ports.

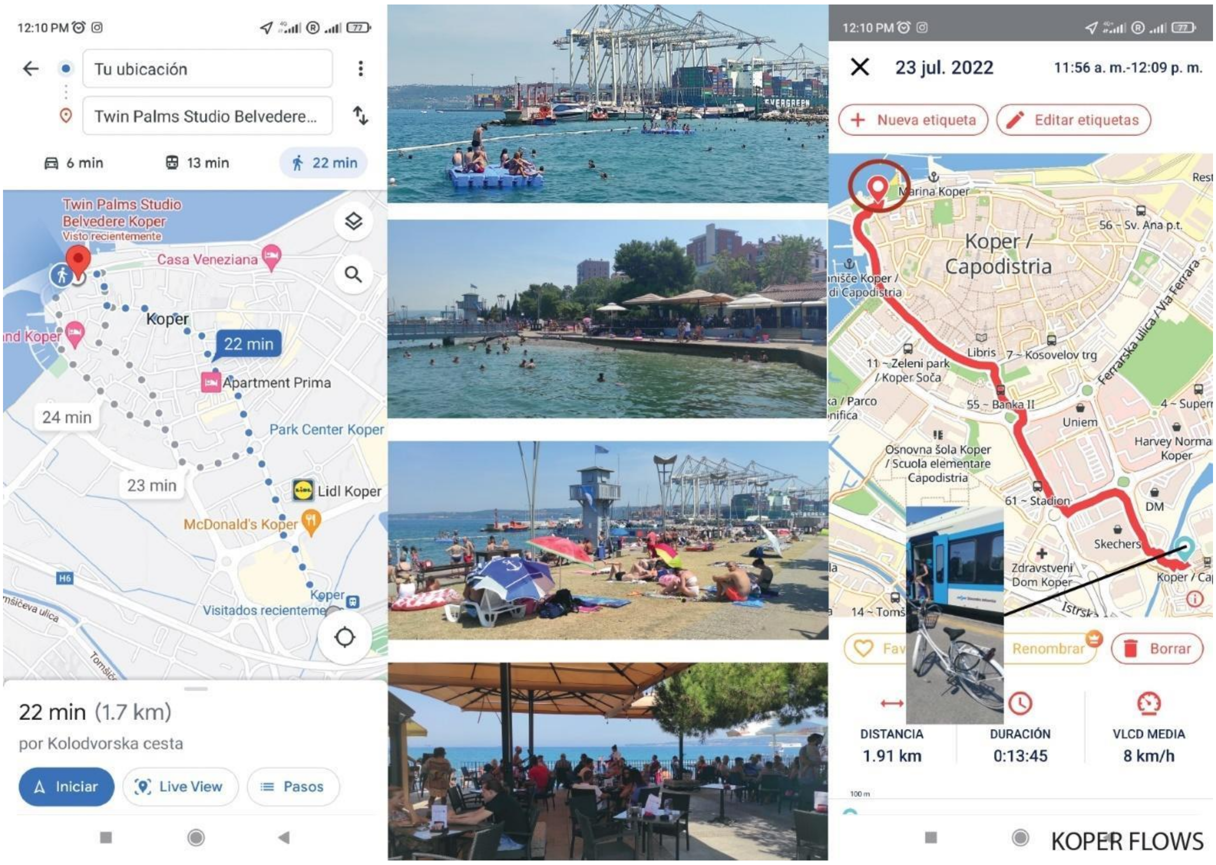

Figure 14: Koper visitor flows

The planning of interventions includes the need for the conservation of natural resources and cultural heritage, tourism, and recreation. Focusing on the importance of the coastal zone in limiting the negative consequences of climate change. Considering the influence of the ecological risk on the environment creates the necessity to develop an appropriate approach for planning activities in the coastal zone. Based on the above, it is clear to see the mobility tendency of the coastline based on tourism or recreational purposes in its majority (Figure 14 and Figure 15).

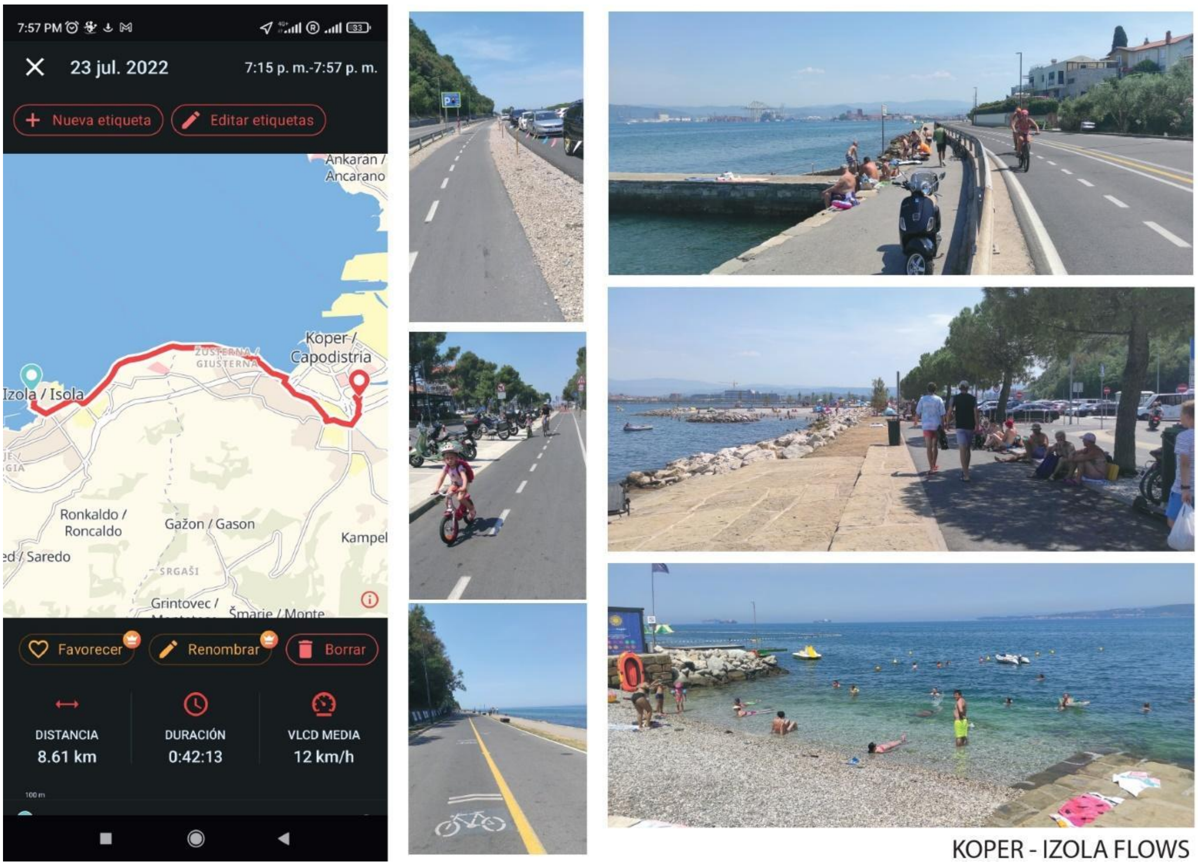

Figure 15: Koper-Izola visitor flows

Nevertheless, the presence of traditional activities such as fishing and sea sports, also need their place in the coastal zone. In this way, it is possible to see the importance of human flows and how they can describe complex scenarios to determine patterns of movement. Relationships between a certain number of visitors into shorter-term mobility as flows in tourism are necessary to understand (Figure 16). The scarceness or absence of data available about fundamental aspects of tourism at a regional level demands more detailed data analysis. Detailed data on different types of short-term mobility of tourism and visitor flows into the coastline of Slovenia is necessary to create appropriate planning and management of the coast area.

Figure 16: Sensor about cyclist flows between Izola and Koper

Preliminary identification of the existing flows of visitors is important, for instance, the traffic between cities on the coastline of Slovenia is based on roads. Due to increasing traffic situations, demands for decongestion and changes have become crucial points of analysis. Overcrowding problems in the touristic areas along the coastline demand detailed analyses of the infrastructure carrying capacity of the space. Even more when the municipalities have the objective of increasing and attracting more tourism to the area.

5 SIMULATION SOFTWARE APPLICATION IN THE CASE STUDY

5.1 Any-Logic Simulation Software

Modeling is a way to resolve real-world problems using a specific language to represent the real system characteristics. It is important to consider that the model is always less complex than the original system. In the specific case of cities, the necessity to explore and understand the urban system's structure and dynamic behaviors under different conditions implies setting and comparing different scenarios to optimize them. This process allows one to find a solution for several urban problems and map it to the real world (Grigoryev, 2021). Simulation modeling requires special software tools that use specific languages. AnyLogic provides a user-friendly interface called JAVA computer programming language- is based on the development environment and contains multipurpose libraries for different scenarios (The AnyLogic Company, n.d.-a).

Any-Logic is a tool for simulations that use several tools to interact with different requirements on a multidimensional scale. AnyLogic assists in three simulation modeling methods: agent-based modeling, discrete event, and system dynamics (The AnyLogic Company, n.d.-a). This software allows the creation of accurate simulation of complex events for example using pedestrian or road traffic models by process flowcharts. A key point is data interoperability between several forms of data storage.

Simulations can recreate complex systems with physical interaction, dimensions, speeds, distance capacity, and timings. Simulations use different methods (multi-method) to map a real-world system with a specific range of abstraction levels. The modeler needs to establish the system's behavior, identify the main variables, their relationships, and dependencies, and recognize a process flow. Determining insights into the system's object behavior is crucial. In this way, it is necessary to start with the recognition of the objects (agents) and defining their behaviors (Figure 17). Any-Logic includes several libraries such as the pedestrian library that work with modeling features of crowd simulation. The pedestrian library is useful to model the behavior of pedestrians in a microscale view by applying an agent-based model approach. Additionally, the pedestrian library can produce simulations about the pedestrian's flow in different physical environments (Mahmood et al., 2017). Finally, this software connects agents to create interactions between their individuals' behaviors with the environment which has its dynamics. The environment represents a specific space generally could be a continuous space such as a geographical map, an orthophoto from some specific place, or a floor plan in a building (The AnyLogic Company, n.d.-a).

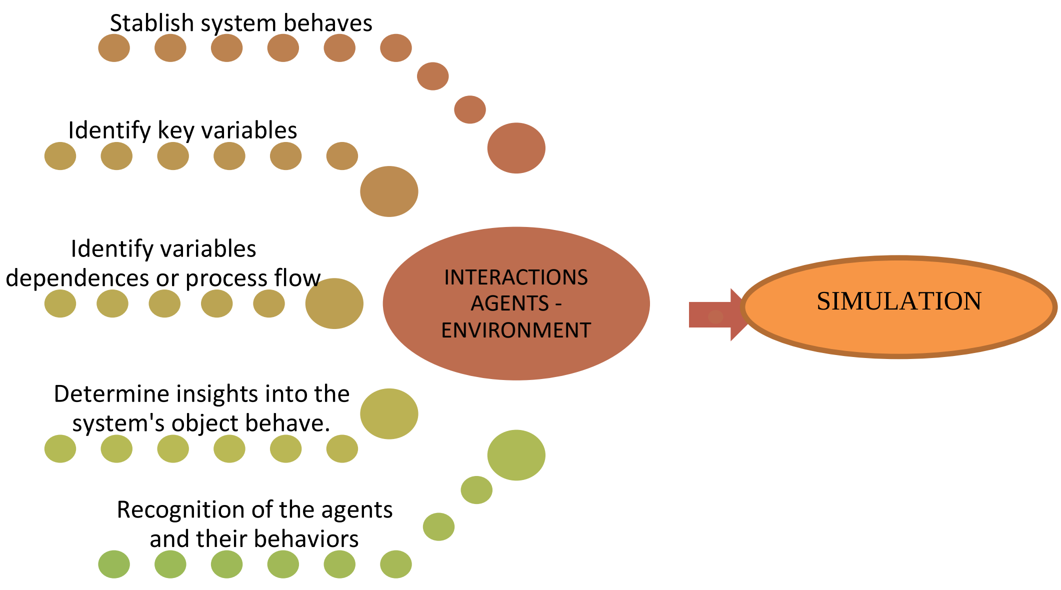

Figure 17: Simulation interactions

5.2 Geographical Information System Models (GIS)

An important resource from Any-Logic software is the possibility to combine simulations with GIS MAP Shapes. These maps are downloaded in **real-time** from an online map service, such as Open Street Map (Figure 18) combined with shape files under the extension.SHP. OpenStreetMap data is normally updated every day. These map resources allow for adding points, routes, and regions. Also, the modeler can apply an agent-based modeling approach to demonstrate the type of agents and their different interactions with the environment defining specific attributes in an overcrowding scenario. Finally, the application of these maps' tools from Any-Logic allows the combination between agents and GIS maps to become part of the environment for all the gents present in the simulations. The modeler can create different scenarios changing the parameters established for agents and the environment.

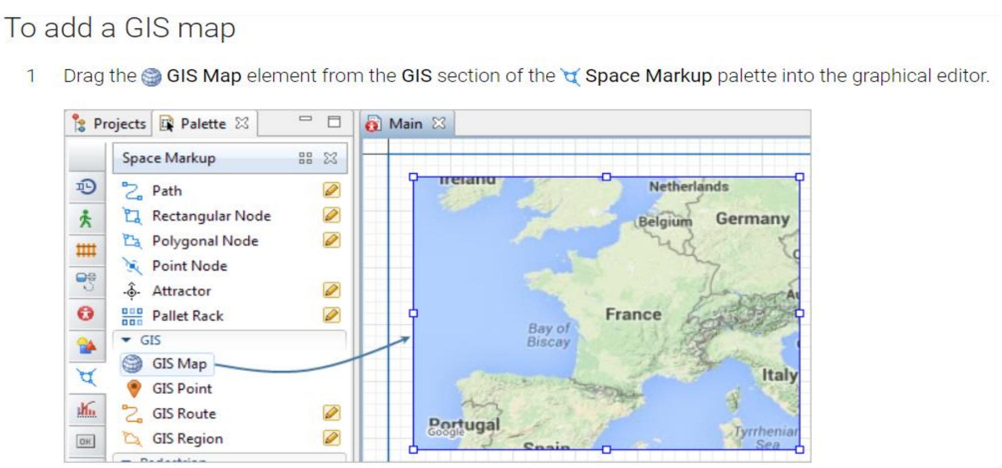

Figure 18: How to add a GIS map. From: (The AnyLogic Company, n.d.-d)

Any-Logic allows the development of details of simulation about logistics and supply chains, social dynamics, and market dynamics among others which are frequently based on geographical information. In this way, it is possible to include GIS maps with specific coordinates. In Agent-Based Models, it is possible to specify GIS areas, or GIS points and let the agents use the space according to their behaviors. It is possible to create routes or regions for a GIS map at the design time; these elements have maximum precision (Grigoryev, 2021). The combination of GIS point, GIS route, and GIS region generates a GIS network (Figure 19). This modeling method can have good advantages for the GIS environment in Any-Logic.

Use the following markup elements to configure locations on the GIS map:

GIS Point — use GIS point to define a city, a shop, or any other point location on the map.

GIS Route — use GIS route to draw routes, roads, and railway tracks, on the map.

GIS Region — use GIS region when you need to define a polygonal area on the map.

Together connected GIS markup elements compose a network.

Figure 19: GIS markup elements. From: (The AnyLogic Company, n.d.-e)

5.2.1 Pedestrian Library Dynamics in GIS space

Any Logic Pedestrian Library creates a simulation of pedestrian flows in the physical environment as a continuous space. Pedestrian models consist of two main components: behavior and environment (The AnyLogic Company, n.d.-a). It is possible to develop models of a pedestrian in buildings or open spaces. Models provide a collection of different statistics, for example, pedestrian density, the performance of service points, length of stay in specific areas, and the problem of evacuation among others (Figure 20).

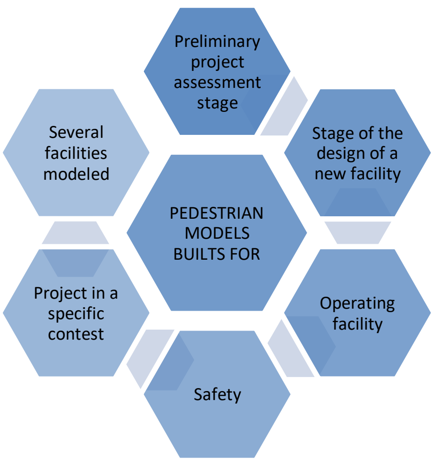

Figure 20: Pedestrian models. From:(The AnyLogic Company, n.d.-f)

The Any-Logic Pedestrian library is a pedestrian simulation that allows crowd analysis accurate models (Figure 21). Allowing detailed analysis and visualizations of crowd flows behave in a determined physical environment. The Any-logic pedestrian library can insert different agent population into the spatial virtual environment defined in the simulation and implements the specific pedestrian flows determined by the modeler who establishes the physical rules (Mahmood et al., 2017). The possibility of replicating this environment in a virtual or online way as GIS maps open the possibilities of testing different scenarios and avoiding inefficiencies in the model.

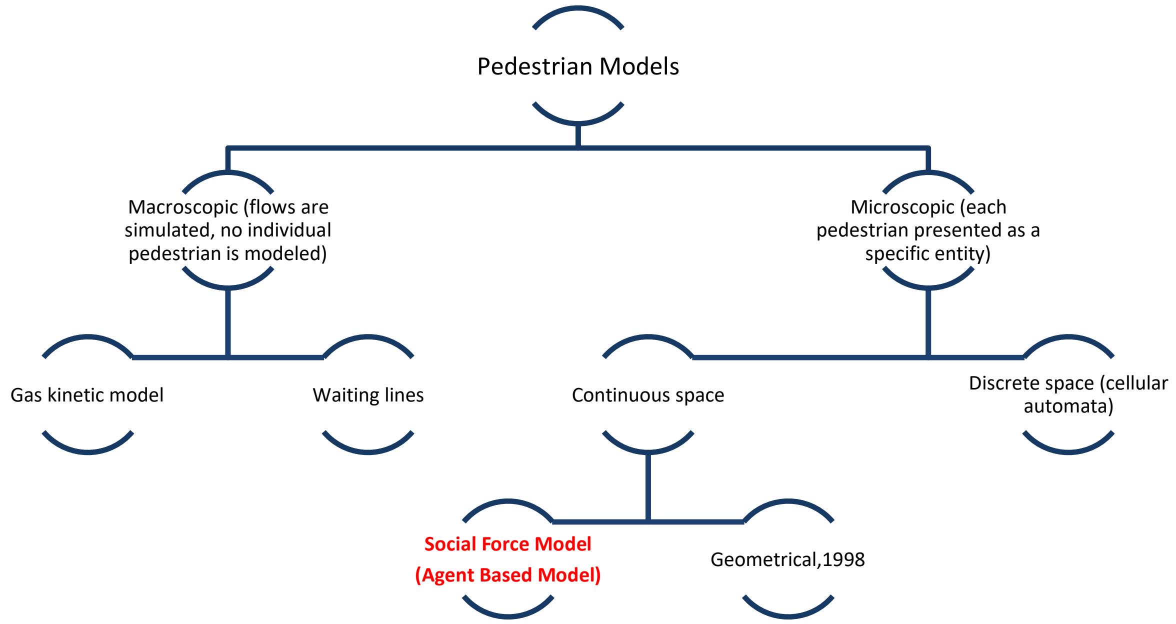

Figure 21: Pedestrian simulation projects for public buildings in France. From: (Koltchanov, 2014)

Any-Logic facilitates the model movements according to specific simulated physical rules. Pedestrians can have individual states, properties, and preferences (The AnyLogic Company, n.d.-a). This tool of the Pedestrian library (Figure 22) is useful in urban landscapes, helping to evaluate capacity, mobility, and accessibility. Through the pedestrian simulation model, it is possible to define the area where pedestrians are allowed to move around. As a result, the crowd management tool will be a useful resource in testing, planning, and determining changes for future scenarios and situations in urban environments. Using pedestrian simulation software is necessary to develop detailed pedestrian flow and crowd dynamics analysis.

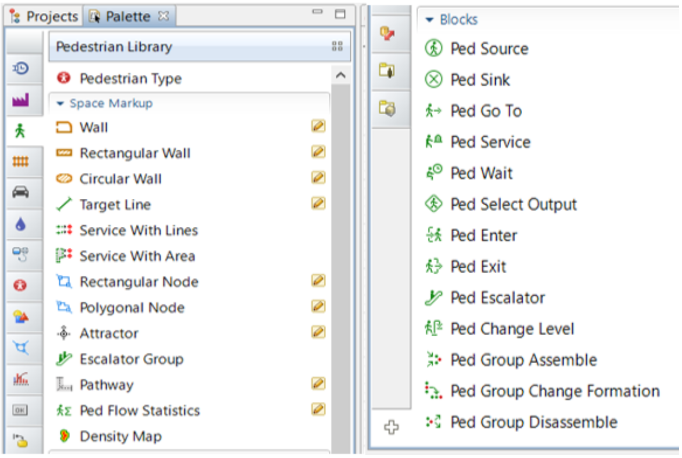

Figure 22: Pedestrian library. From: (The AnyLogic Company, n.d.-f)

5.2.2 Road Traffic Library Dynamics in GIS space

The Road Traffic (Figure 23) library allows the development of detailed models, simulations, and visualizing vehicle traffic. Using visual space markup shapes such as roads, intersections, parking lots, and stop lines for a detailed drawing of road networks. Any-Logic gives the option to obtain the location of different infrastructure points such as parking lots, restaurants, and pharmacies using the GIS map tool. Create a route according to OpenStreetMap data information and connect these different routes in a road network. Another useful resource of simulations with the Road Traffic Library in Any-Logic is the analysis of parking lots. One of the main problems in the urban context is organizing permanent car storage places. Even more so in tourist places where the demand grows between visitors and residents. Traffic congestion increases emissions of harmful substances (Rahman et al., 2021). In the case of parking, drivers can be more distracted than other users when searching for a specific parking space. This situation can be a danger for other users such as cyclists and pedestrians (Magdin et al., 2021). Under those circumstances, running simulations about the use, capacity, and congestion in parking lots are useful tools for planning future parking spaces in the cities.

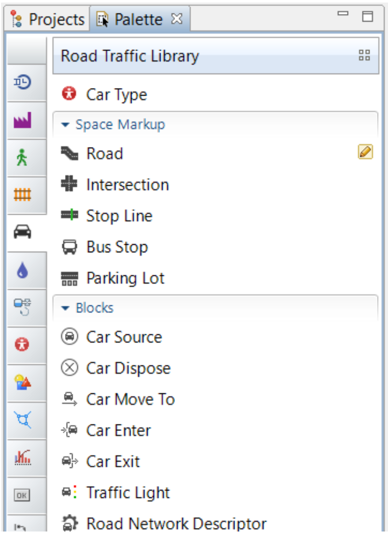

Figure 23: Road traffic library. From: (Road Traffic Library, n.d.)

5.3 GIS Data Load and Display

Data of the WGS84 coordinate system can be displayed in Any-Logic in combination with shapefile data. In this way, it is possible to establish the map projection. In a GIS environment, it is possible to establish the scale and center location on the map when using the zoom out or zoom in. This center position and scale can be changed if there is a necessity in the simulation process.

After importing GIS data. It is possible to complement this resource tool with specific shapes from OpenStreetMap (Figure 24). These files are actualized constantly online, and it is possible to see the detailed time of modified data when the file is downloaded. For the thesis case study, Slovenia's latest free shapes (Figure 25 and Figure 26) were taken from OpenStreetMap Data and opened in ArcGIS for visualization.

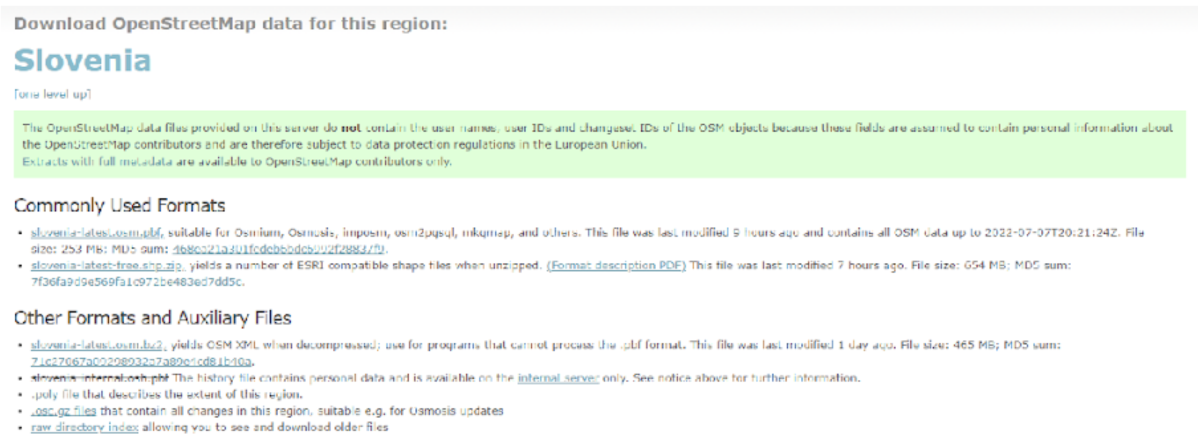

Figure 24: Slovenia download Open Street Map. From:(OpenStreetMap, 2022)

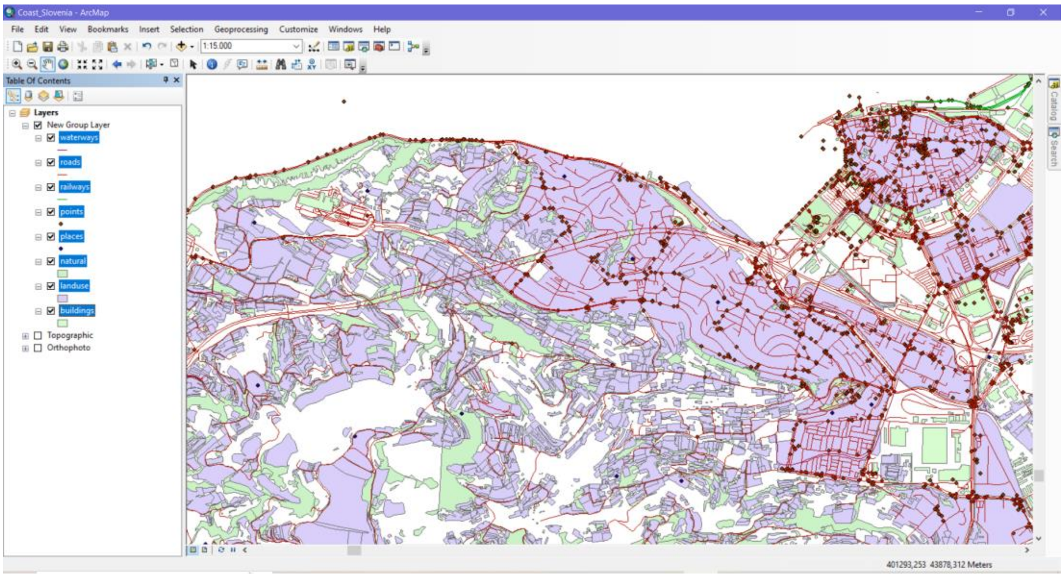

Figure 25: Slovenia download OpenStreetMap in ArcGis

The main layers downloaded are:

- Waterways
- Roads
- Railways
- Places
- Natural
- Land Use
- Buildings

Additionally, different shapes from (the Ministry of the Environment and Spatial Planning of the Republic of Slovenia, 2022) were analyzed in Arc-GIS Software to understand the information available for a better comprehension of the urban context. The layers downloaded are:

- Routes
- Transport Network
- Utility Services
- Structures
- Land in special use
- Land Cover
- Hydrography
- Building
- Orthophoto.

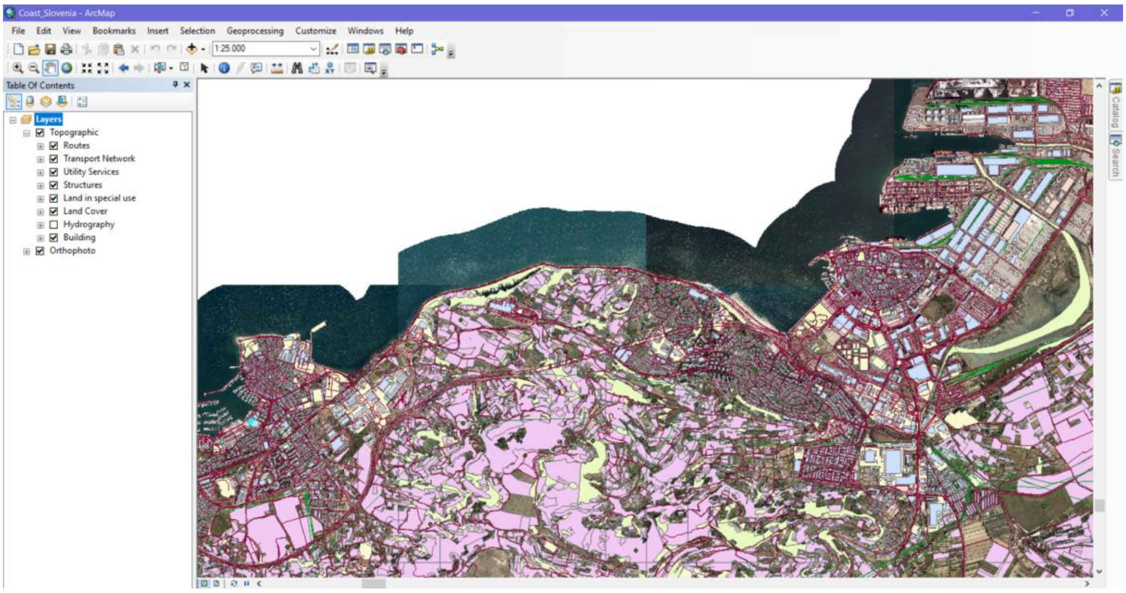

Figure 26: Map of shapefiles selected from (Ministry of the Environment and Spatial Planning of the Republic of Slovenia)

5.4 Agent Settings

Anylogic allows the combining of shapes data information with the importing GIS data. This creates the GIS space or environment where agents are set and defined with an initial quantity, speed, and position. To make agents live in GIS space it is necessary to determine different specific parameters such as quantity, initial speed, names, and the exact position of agents (Li et al., 2011). For the case study of the Slovenia coast area, simulations in various scenarios scales are present in the pedestrian model and road traffic model. Agents' details are defined in each scenario, for each group:

- Pedestrians
- Cyclist
- Skater

, and for road traffic simulations agents:

- Vehicles
- Parking lots

5.5 Pedestrian simulation models:

5.5.1 Scenario 1: Koper visitor flows

This simulation aims to show the spatial relation between three different kinds of visitors in the coastal area of Koper. These visitors are classified into three agent categories: pedestrians, cyclists, and skaters. Each of these agents has its parameters established for their behavior in the simulation. For this scenario, the GIS map tool from Any-Logic is used to locate three main areas: Koper center – Centralni mestni park, and the beach area (Figure 27).

Figure 27: Real environment selected for scenario 1: Koper visitor flows

The specific pedestrian space markup from the pedestrian library is used to draw the walls which will determine the specific area where visitors can move and stay for some time (Figure 28). Different pathways are determined for the connection of these three main areas into the environment simulation.

Figure 28: Virtual environment selected for scenario 1: Koper visitor flows

The GIS map routes are requested from the OpenStreetMap server. The routing method for agents selected is the shortest (Figure 29). Additionally, a shapefile of roads from Slovenia's latest free shapes was taken from OpenStreetMap Data and added to the GIS map. These graphical resources help to determine the specific areas and routes necessary for the simulations.

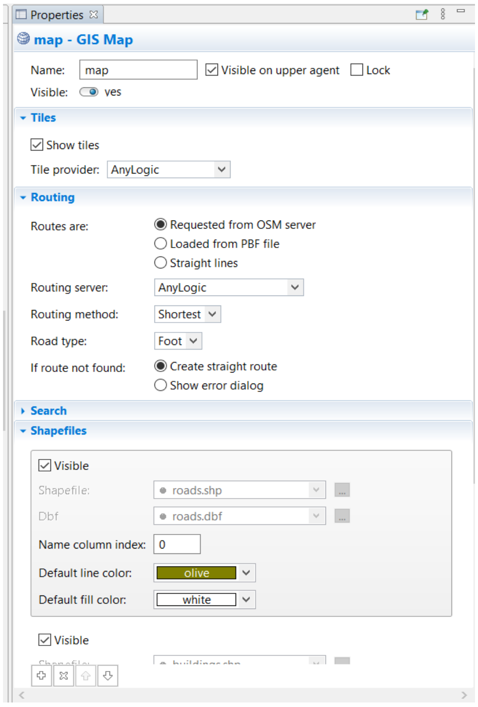

Figure 29: Parameters selection for the GIS map environment for scenario 1

After establishing the simulation environment with the pedestrian library, it is the moment to determine the three agents in the environment (Figure 30 and Figure 31). First, pedestrians are defined with an initial number of 1000 agents and an initial speed of 0.4 m/s. Second, the cyclists with an initial number of 400 agents, and an initial speed of 2 m/s. Third, the skaters with an initial number of 250 agents and an initial speed of 1m/s. These values can be changed in the simulation according to the different scenarios and relations to the environment.

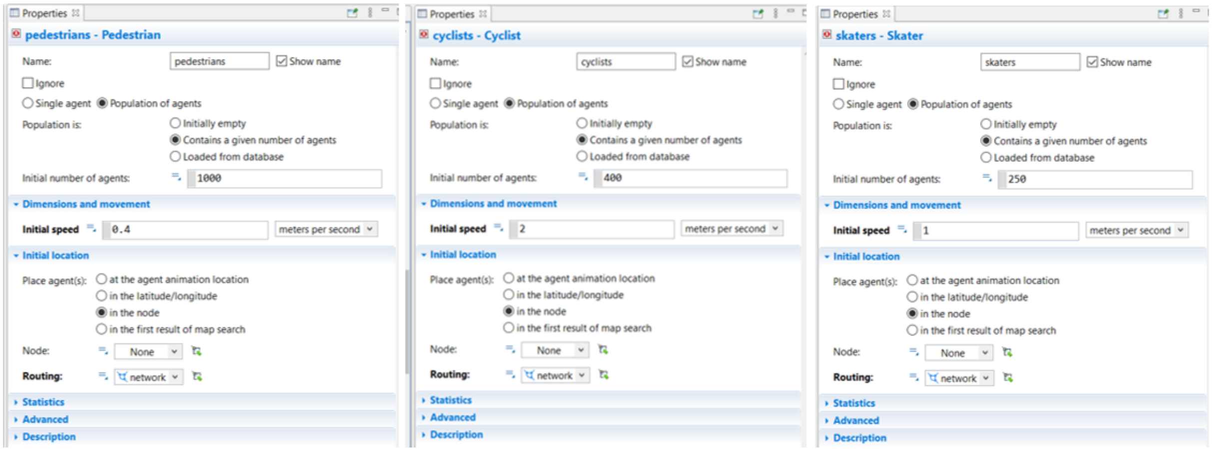

Figure 30: Properties selected for each agent

Flowcharts are determined per each type of agent:

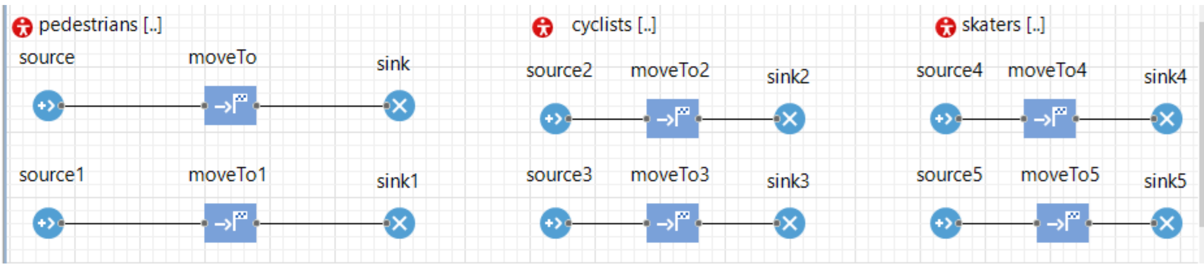

Figure 31: Flowcharts determined per each type of agent

Source: This parameter allows determining the arrivals by "(interarrival time, arrival table in database, rate, rate schedule, arrival schedule, call of injecting () function)" (The AnyLogic Company, n.d.). Additionally, the arrival rate number of agents per hour. The location of arrival is determined by the GIS node and its speed. Each agent has a different arrival rate, location of arrival, and speed established in their specific flowcharts (Figure 32).

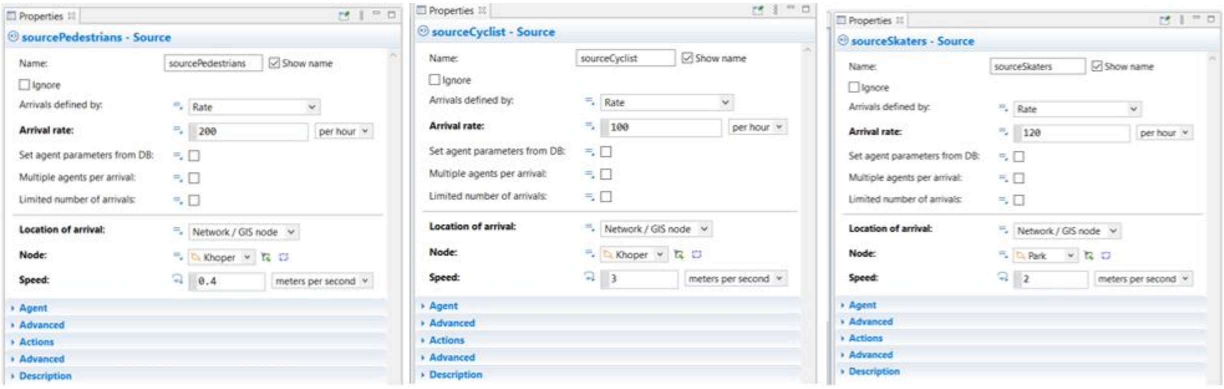

Figure 32: Source selected per each agent

move to: Specify the destination of the agent into the network by GIS node and the movement definition (Figure 33).

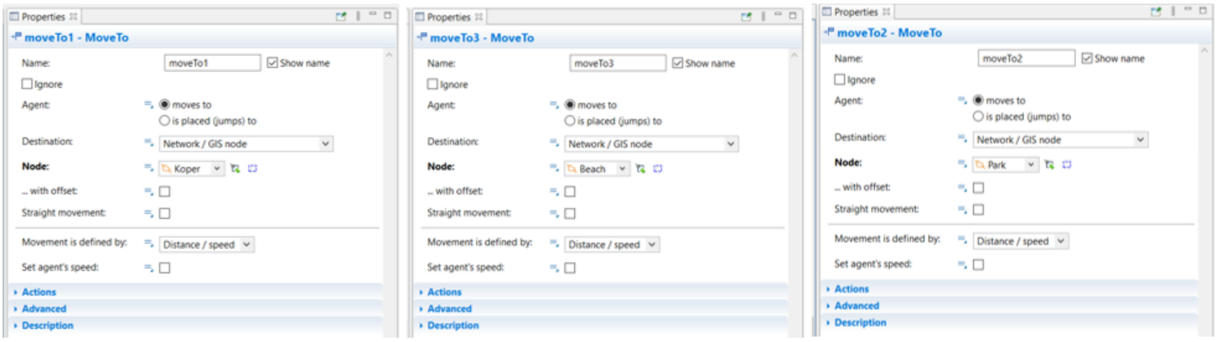

Figure 33: move To parameters selected for each agent

sink: It is the end of the flowchart, which allows closing the simulation process.

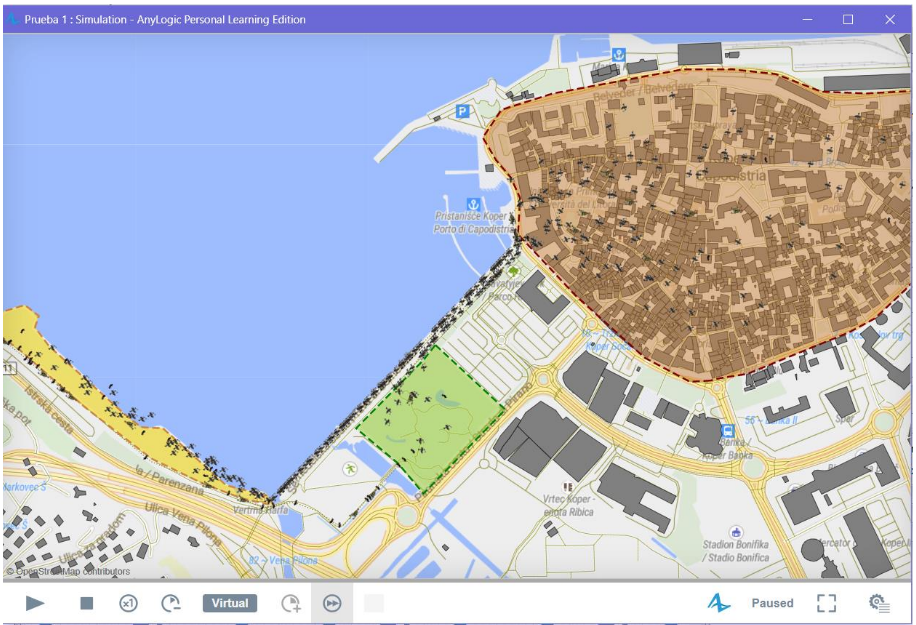

Figure 34: Simulation scenario 1: Koper visitor flows

This simulation (Figure 34) is a general view of the agent's behavior in a defined environment. AnyLogic agents allow having several types of agents with different parameters and behaviors in the same environment. Locations, speeds, and amounts can be defined and changed according to the requirement of each scenario simulation.

To develop in more detail, the agent's movements between specific nodes. Several restaurants and two more beaches are selected for the scenario area (Figure 35). Additionally, two shape layers: roads and buildings are included with the GIS map given from the GIS tool.

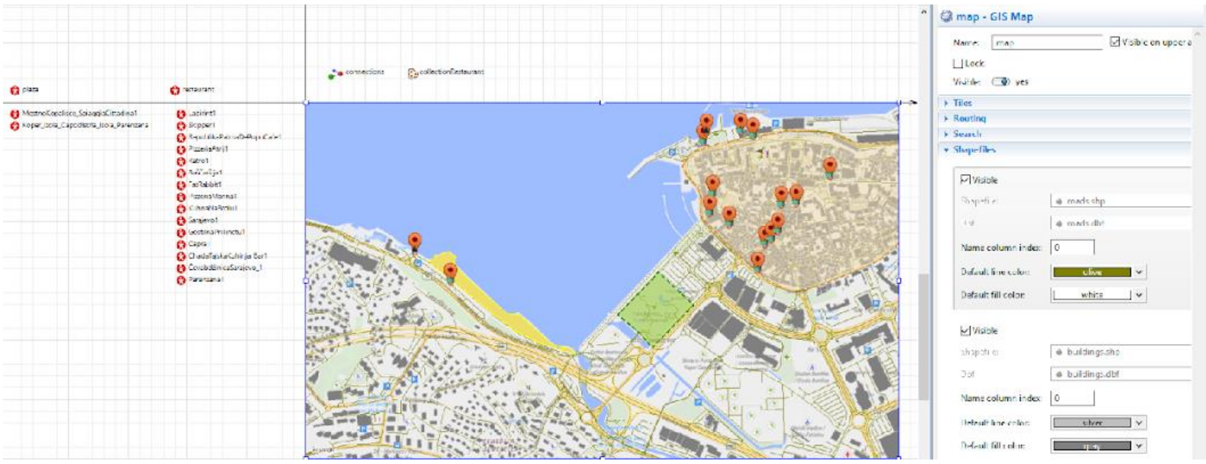

Figure 35: Identification of restaurants and beaches in the scenario area of simulation

It is possible to define different flows according to the type of agents. Aspects such as schedule are defined for each type of agent. The schedule allows the determination of specific dates, hours, and values per range of time to be analyzed in the simulation (Figure 36).

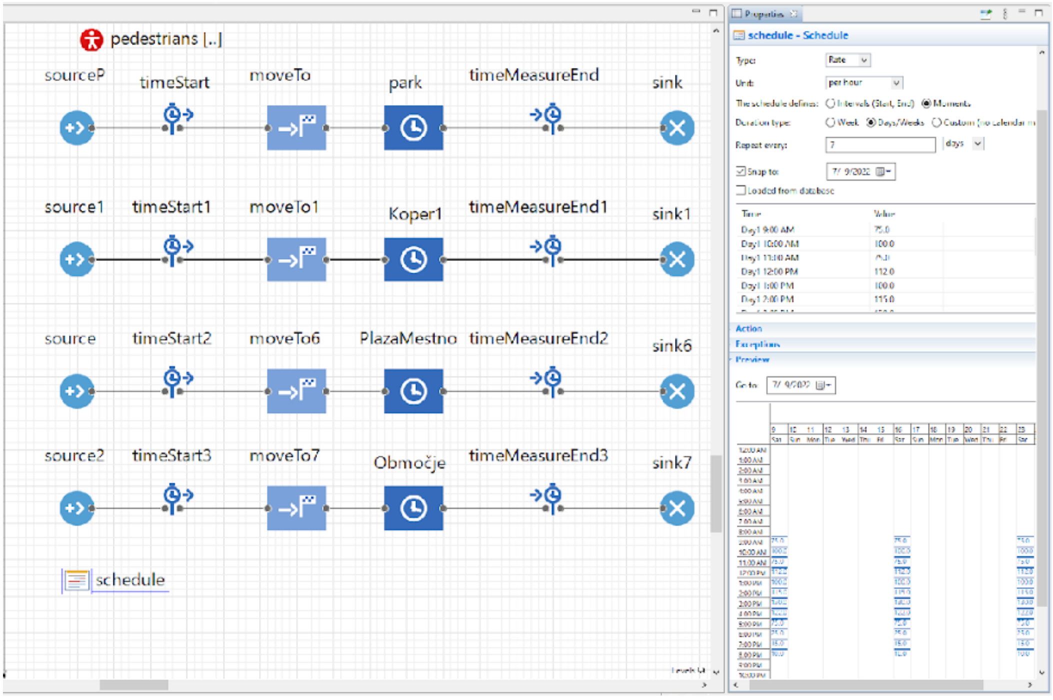

Figure 36: Pedestrian schedule

The data analysis is focusing on the three agents: pedestrians, cyclists, and skaters (Figure 37). Results of statistics about places utilization use data that collects statistics about the object utilization. Time statics are determined by blocks TimeMeasureStart and TimeMeasureEnd. These items are used for measuring the time spent by agents in a specific flowchart section. “The TimeMeasureStart block stores the time when an agent passed through it, while the TimeMeasureEnd block measures the time where an agent stays inside the determined section of the flowchart after crossing the specific TimeMeasureStart block.” (Collecting Utilization Statistics | AnyLogic Help, n.d.). Finally, Histogram PDF (probability distribution function) is determined for shows using vertical bars each corresponding to a particular interval. These bar charts are identified with specific heights about the density (or number) of different data samples included in the interval. (Histogram | AnyLogic Help, n.d.)

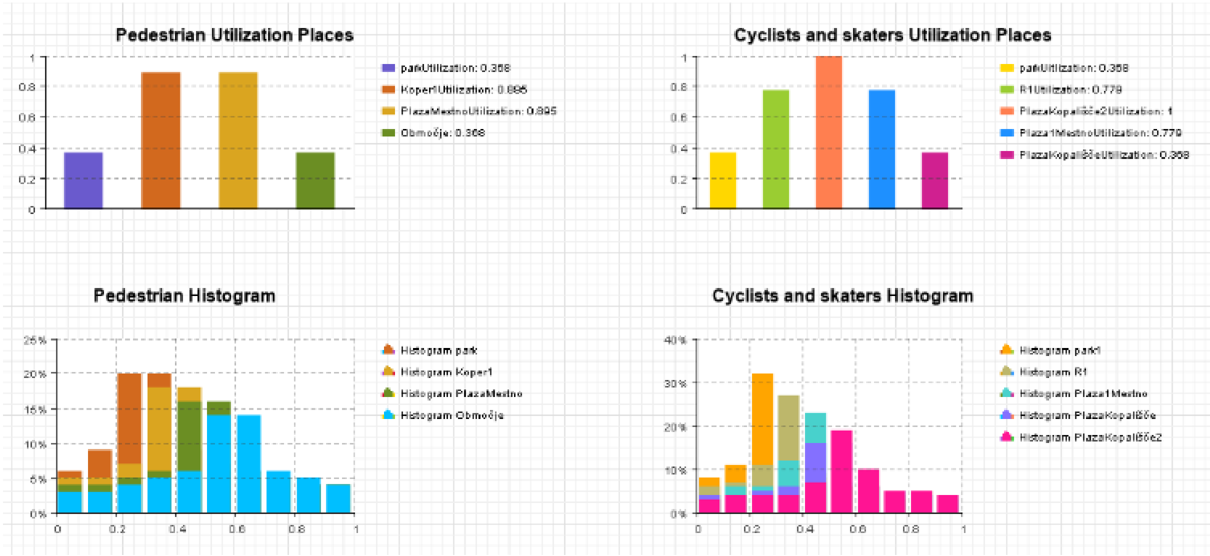

Figure 37: Statics results of agents

As a result, Scenario 1 (Koper visitor flows) (Figure 38) simulation allows for analyzing different flows between specific touristic nodes. Established agents (pedestrians, cyclists, and skates) with their specific characteristics. People influenced with their flows the spatial order in the city of Koper. The simulation allowed us to determine different flows of people according to specific day time and the number of agents, speeds, dwell time in specific nodes, and crowding moments between the daily schedules. All this data is an important resource for recognizing the dynamics of space. Determine specific relations between infrastructure and people according to data established according to visualizations on the site. Under those circumstances, it is possible to see the necessity of processing data from visitor flows, counting the number of users in the space, and being able to connect this data with the simulation in real time.

Figure 38: Simulation result about weekend time

5.5.2 Scenario 2: Izola beach and pedestrians

This scenario aims to visualize the agent’s behavior when selecting different places to stay and the wait time spent in these places. Overcrowding situations will be analyzed to understand how determined touristic places influenced the concentration of visitors. Analyzing these flows and crowding situations can provide important feedback for urban planning decisions about urban space distribution.

Figure 39: Real scenario 2: Izola beach pedestrians

For this simulation, an image from Orthophoto obtained by (the Ministry of the Environment and Spatial Planning of the Republic of Slovenia, 2022) is inserted as the scenario for the simulation. This image shows part of the historic coastline and popular tourist hub of Izola. Places as: part of Delamaris Beach, Plaža slepih in slabovidnih, Slovenska obala, and Svetilnik Beach Izola were selected as the hot spots of this touristic area (Figure 39 and Figure 40).

Figure 40: Popular tourist hub spots of Izola

Then, the pedestrian library from Any-Logic is used to draw the main area where pedestrian flows are developed (Figure 41). Hot spots are drawn and determined as places to stay with different ranges of permanence.

Figure 41: Environment for scenario 2: Izola beach pedestrians

The flowcharts are established with the specific parameters for the pedestrians (Figure 42):

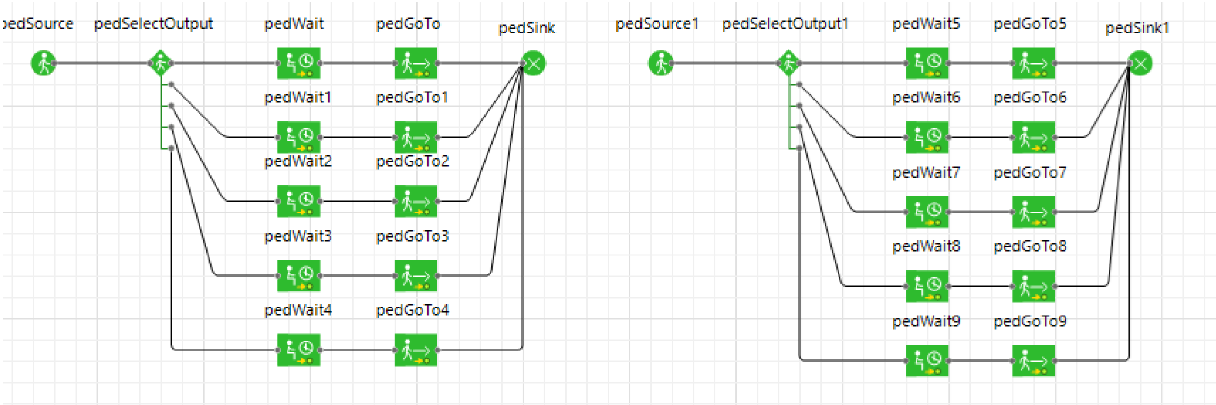

Figure 42: Flowcharts for scenario 2: Izola beach pedestrians

Source: This parameter allows for determining the place of set the agent which could be established by line, point, or node. Additionally, the arrival rate number of agents by a determined time, and speed (Figure 43).

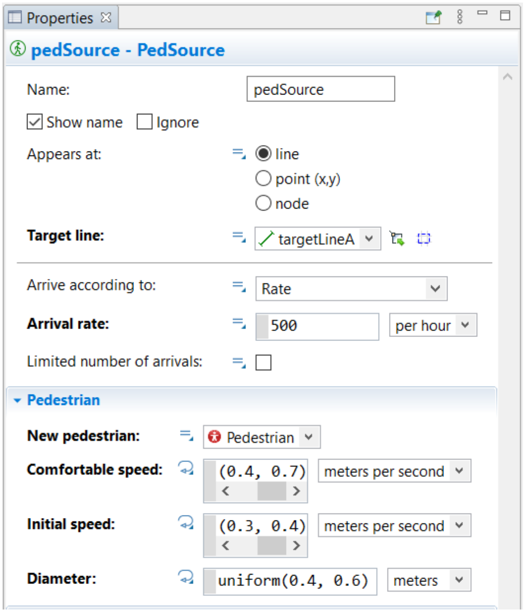

Figure 43: Pedestrian source properties

selectOutput: Determine the probabilities, conditions, or exit numbers for agents (Figure 44).

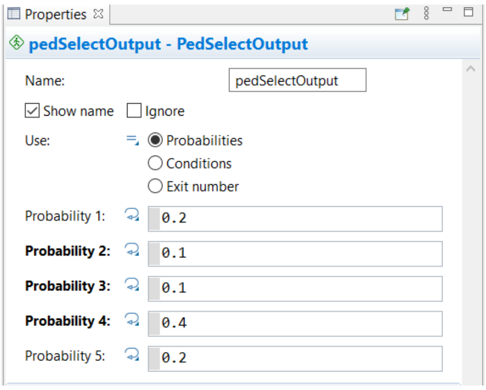

Figure 44: Select output pedestrian properties

pedWait: This allows us to determine the waiting location by node, line, or point, the attractor choice, and delay time (Figure 45).

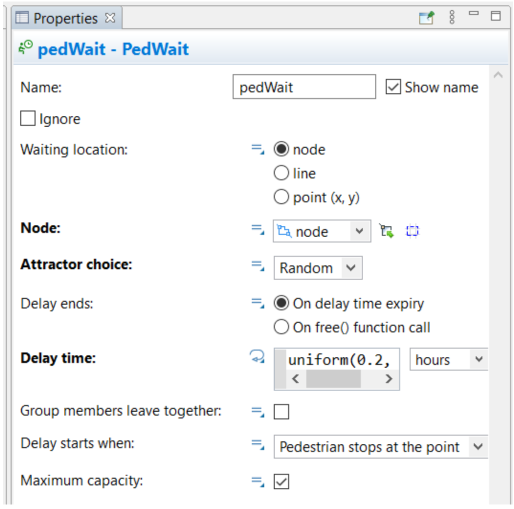

Figure 45: pedWait pedestrian properties

pedGoTo: Indicates the line, point, or node where an agent will move as a destination (Figure 46).

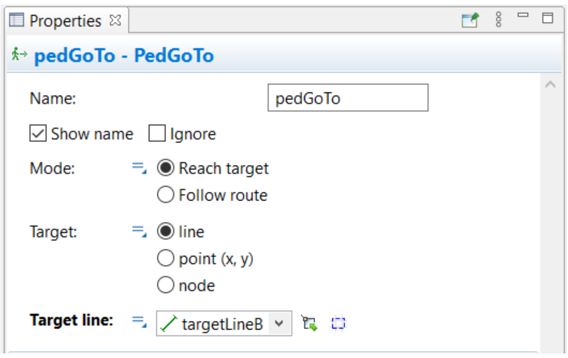

Figure 46: pedGoTo pedestrian properties

sink: It is the end of the flowchart, allowing us to close the simulation process.

Also, a Density Map tool from a pedestrian library is used. This resource tool helps to collect statistics about the density of moving agent's units in the simulated environment space and displays this data information on detailed animation determined by colors as a density map. Each color is determined by every point marked into the space corresponding to the actual density. In the meantime, the density map keeps constantly repainting and changing colors concerning the density change of values (Figure 47). In other words, color changes according to the density changes. In case there is no presence of agents in the space the area will not be painted with any color. The color scheme is defined by different colors but the main one is a red color which indicates a high density (by default red color it is equal to 1.5 units/m2). Finally, the blue color shows low densities (The AnyLogic Company, n.d.-c). This is a flowchart result simulation into a one-hour time run of simulation (Figure 48):

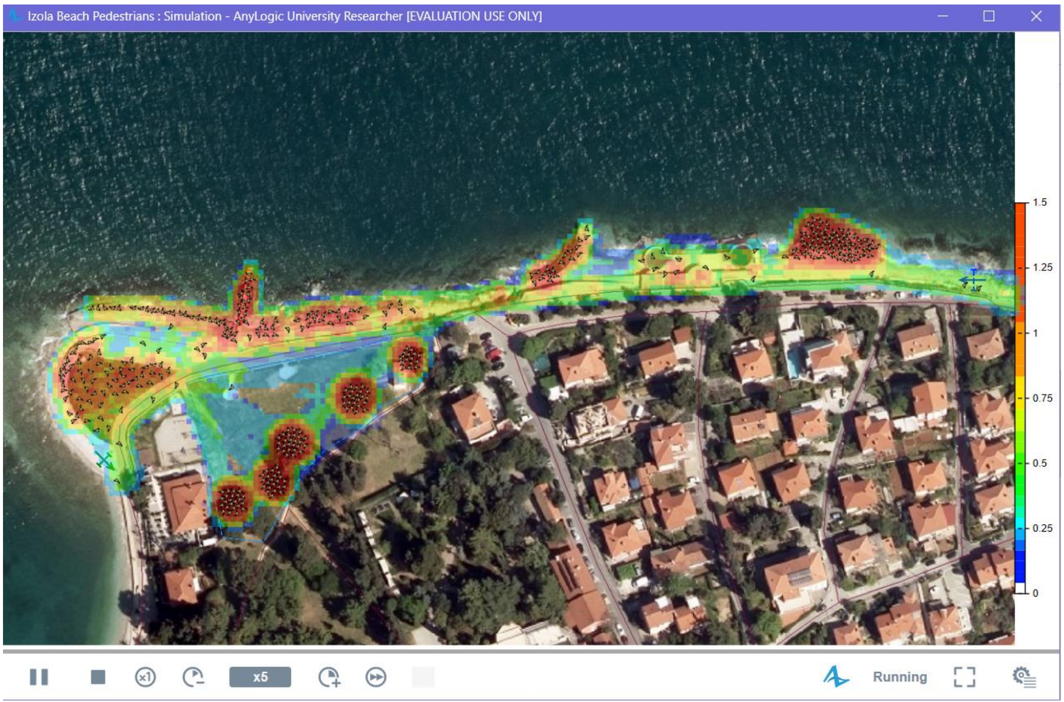

Figure 47: Density map simulation of scenario 2: Izola beach pedestrians

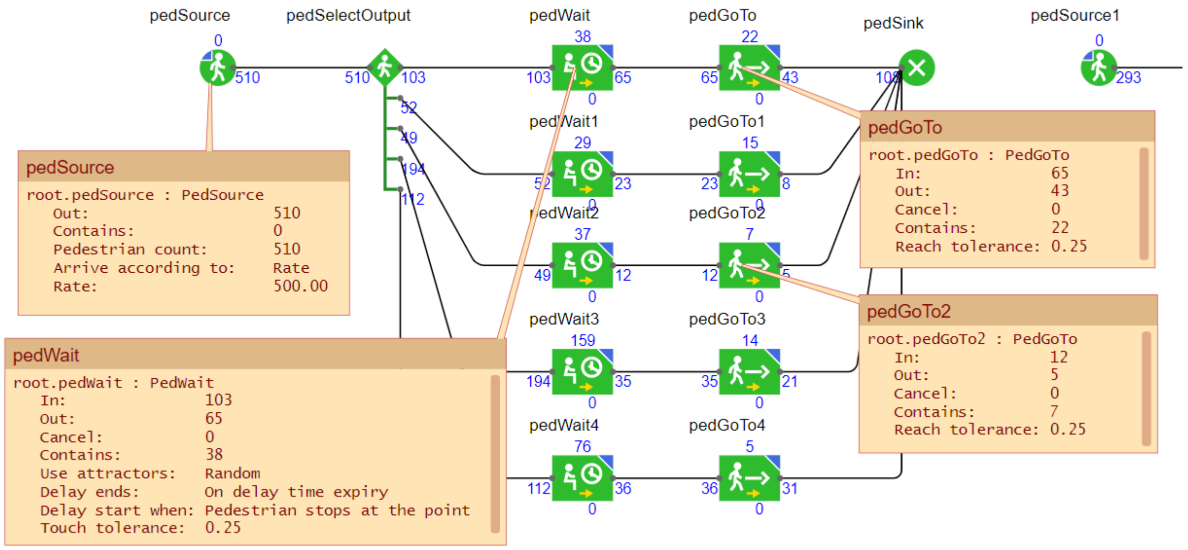

Figure 48: Flowchart result simulation of scenario 2: Izola beach pedestrians

The pedestrian library has a useful tool called Ped Flow Statics. This tool allows a collection of statistics about the number of pedestrians passing the section established by a line in the environment of simulation. Ped Flow Statics allows configured element parameters for counts of a pedestrian crossing in both directions and one direction. It is possible to use the element's traffic, and intensity functions. These functions show the values correspondingly to pedestrian traffic and intensity (Figure 49). "Traffic static is calculated as the number of pedestrians that passed the line section determined by a specific direction. Also, intensity is calculated as the traffic value divided by the line length (in meters). This one is measured in pedestrians/(hour*meter)" (The AnyLogic Company, n.d.-f)

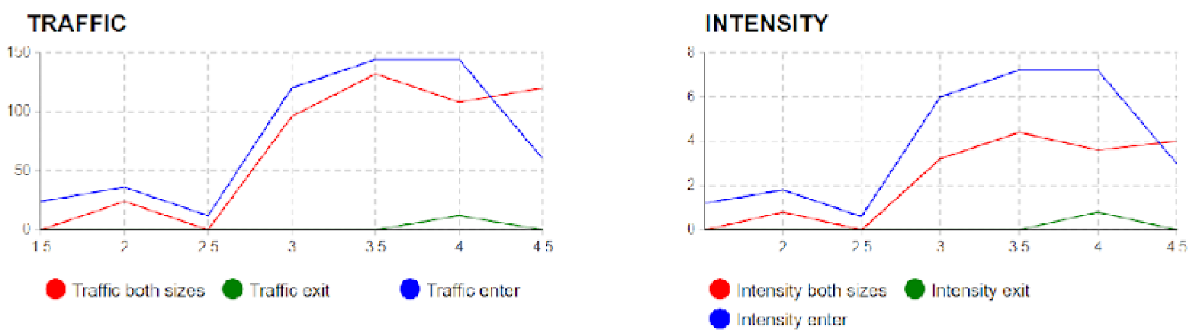

Figure 49: Pedestrian Flow Statics

As a result, two simulations were developed in a specific two-time scenario: first on a weekend day on Saturday (07-23-2022) summer season (Figure 50) and second on a weekday (05-02-2022) spring season (Figure 51). These schedules are determined following the intensity of visitor flows per hour on a specific day. The demand for tourist places usually is higher in the summer season than in the spring season. Thus, with the two scenarios simulations, it is possible to have a clear visualization of the crowd areas according to season and specific time hours in the day.

Figure 50: Scenario in summer season at 12:00 pm

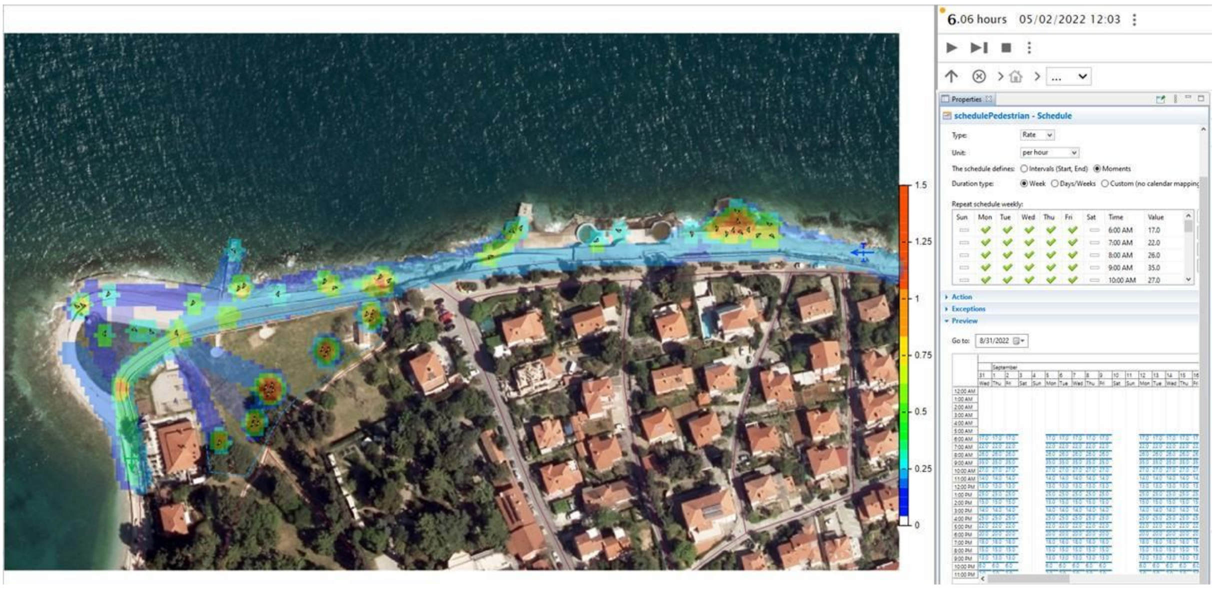

Figure 51: Scenario in spring season at 12:00 pm

5.6 Road traffic simulation models:

5.6.1 Scenario 1: Parking Lots Koper with GIS location

GIS parking Lots location: For this scenario, the GIS tool from Any-Logic is used to recognize the different locations of parking lots in the area selected on the map. Agents' settings of Parking Lots are created and set on the GIS map (Figure 52 and Figure 53).

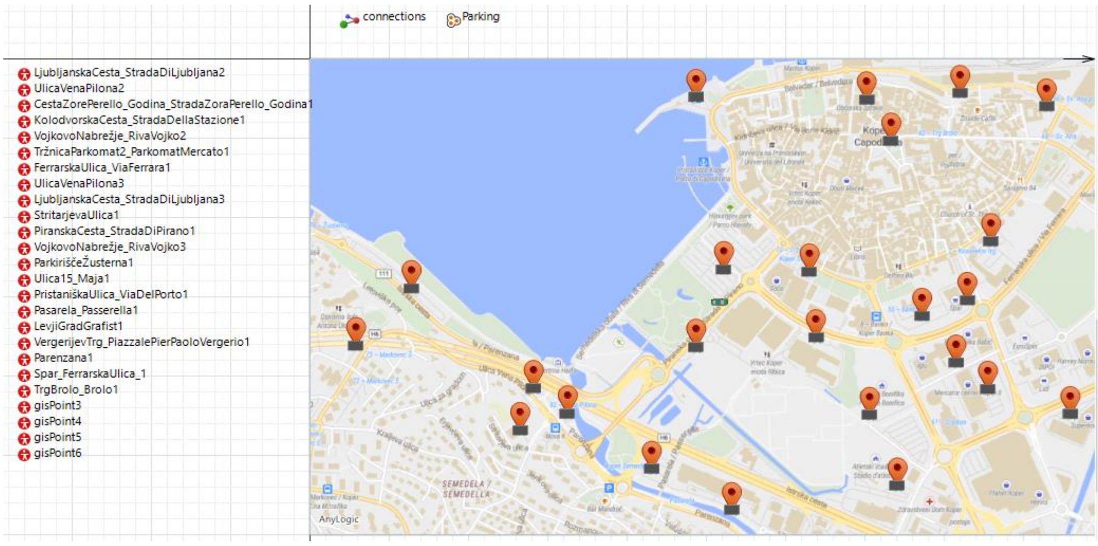

Figure 52: The agent's parking lot and car are established based on GIS data

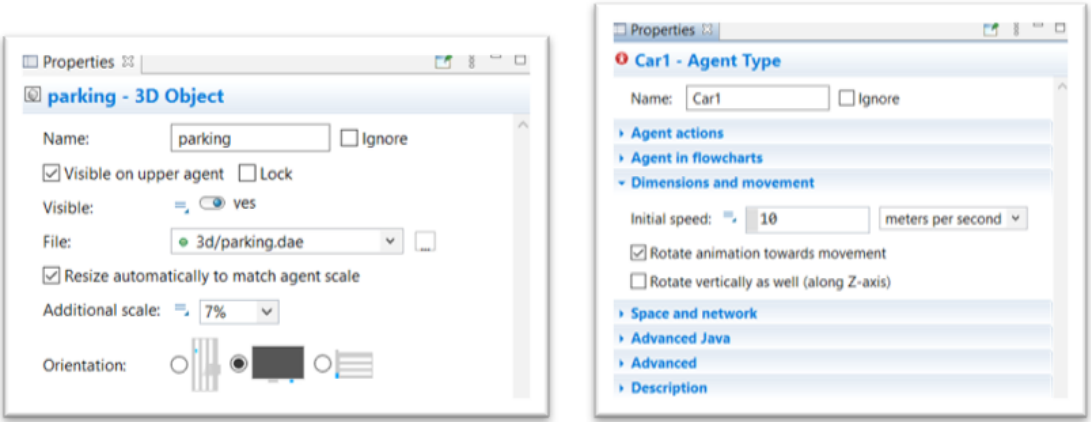

Figure 53: Parking and car properties

Flowchart establishes for the simulation (Figure 54):

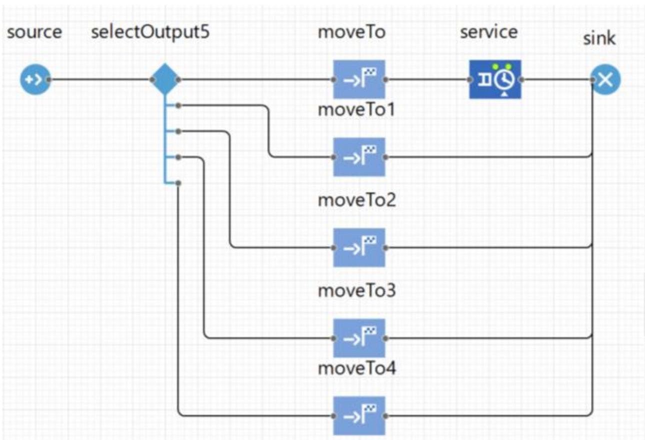

Figure 54: Simulation flowchart

- **Source:** This parameter allows for determining the arrivals. Additionally, the arrival rate is established at 300 agents per hour in this model (Figure 55).

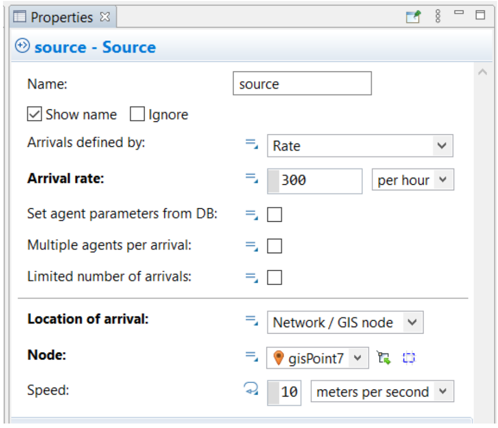

Figure 55: Source properties

- **selectOutput5:** Determine the probabilities, conditions, or exit numbers for agents (Figure 56).

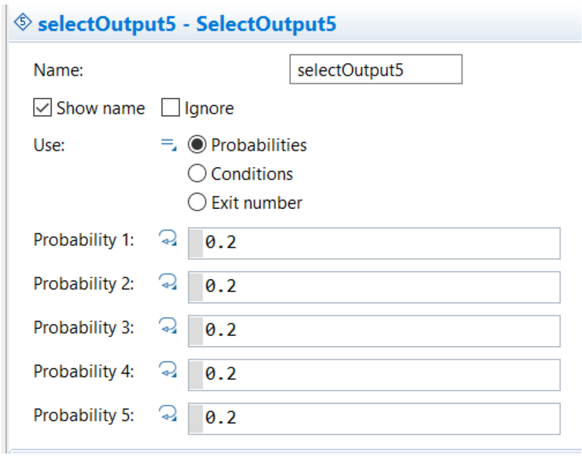

Figure 56: Select output properties

Figure 56**move To:** Specify the destination of the agent into the network by GIS node and the movement definition (Figure 57).

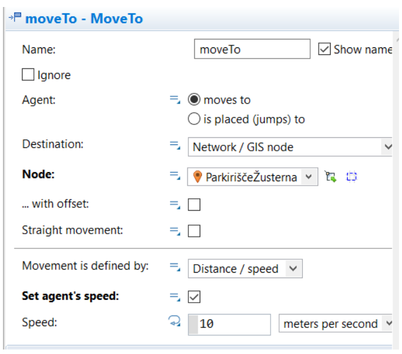

Figure 57: move To properties

- **service:** This parameter establishes the Queue capacity of the service into a triangular delay time (Figure 58).

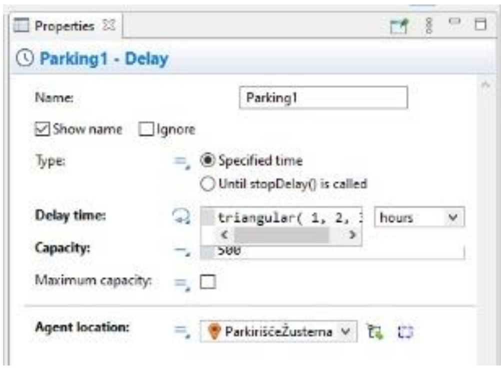

Figure 58: Service properties

- **sink:** It is the end of the flowchart, which allows the closing of the simulation process.

Also, to the main flowchart, it is possible to establish graphics for collecting statics (Figure 59). Adding blocks as Delay. The utilization type statics is possible to use when the Delay block is created. Each Delay block has a (stats. Utilization) which collects statistics on the agent utilization (The AnyLogic Company, n.d.-b). In the case of Scenario 1: Parking Lots Koper with GIS location, the block delay is configured as the time spent in the parking lot, giving as result the time of the parking utilization.

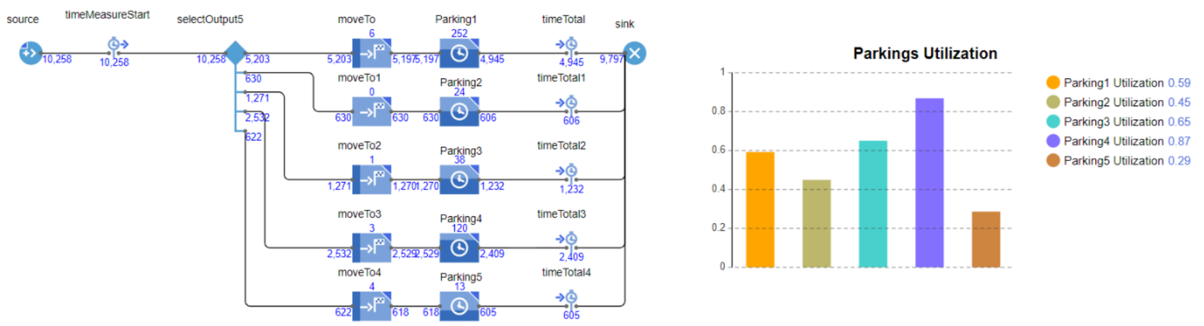

Figure 59: Parking utilization statics

Additionally, it is possible to establish the time statistics using AnyLogic (Figure 60) " Process Modeling Library blocks TimeMeasureStart and TimeMeasureEnd(car1)". (The AnyLogic Company, n.d.-b)

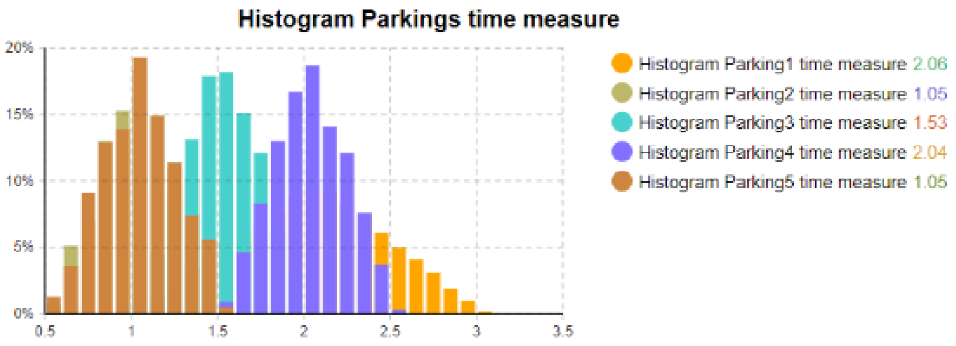

Figure 60: Histogram parking time measure

Finally, simulations are developed in two different time scenarios, weekend days (Figure 61) and weekdays (Figure 62). The intensity of vehicle flows affects the capacity of parking lost according to the percentage of their utilization range. These simulations are useful for determining the capacity of parking lots according to the demand of visitor flows.

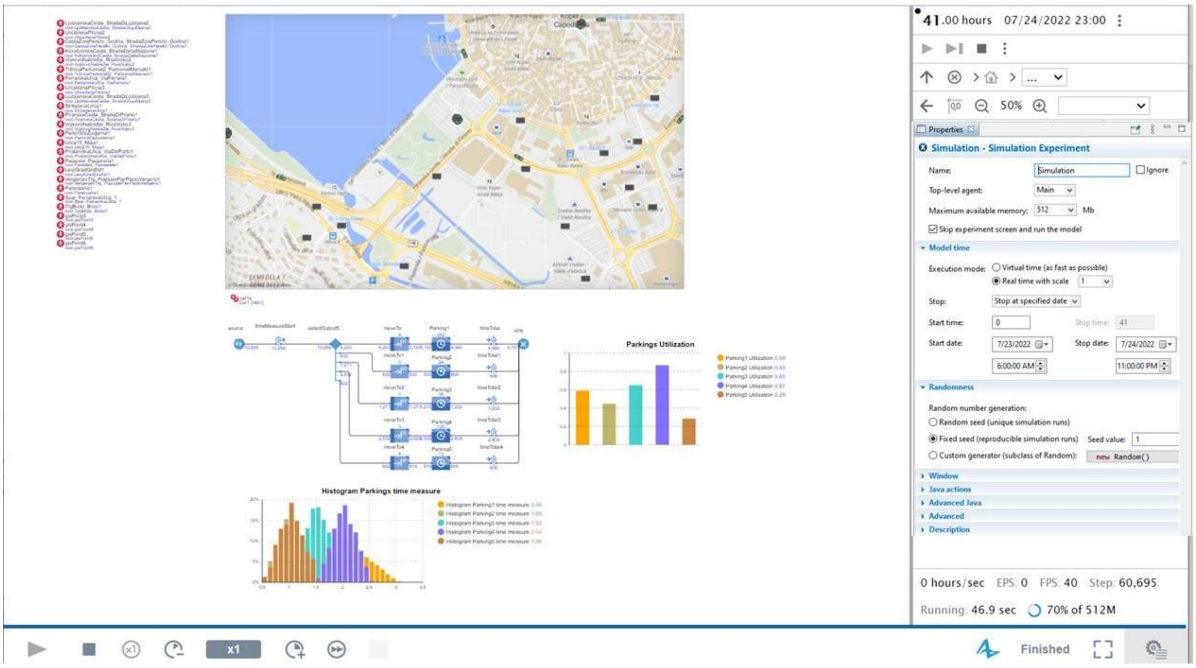

Figure 61: Scenario of parking lots on weekend days

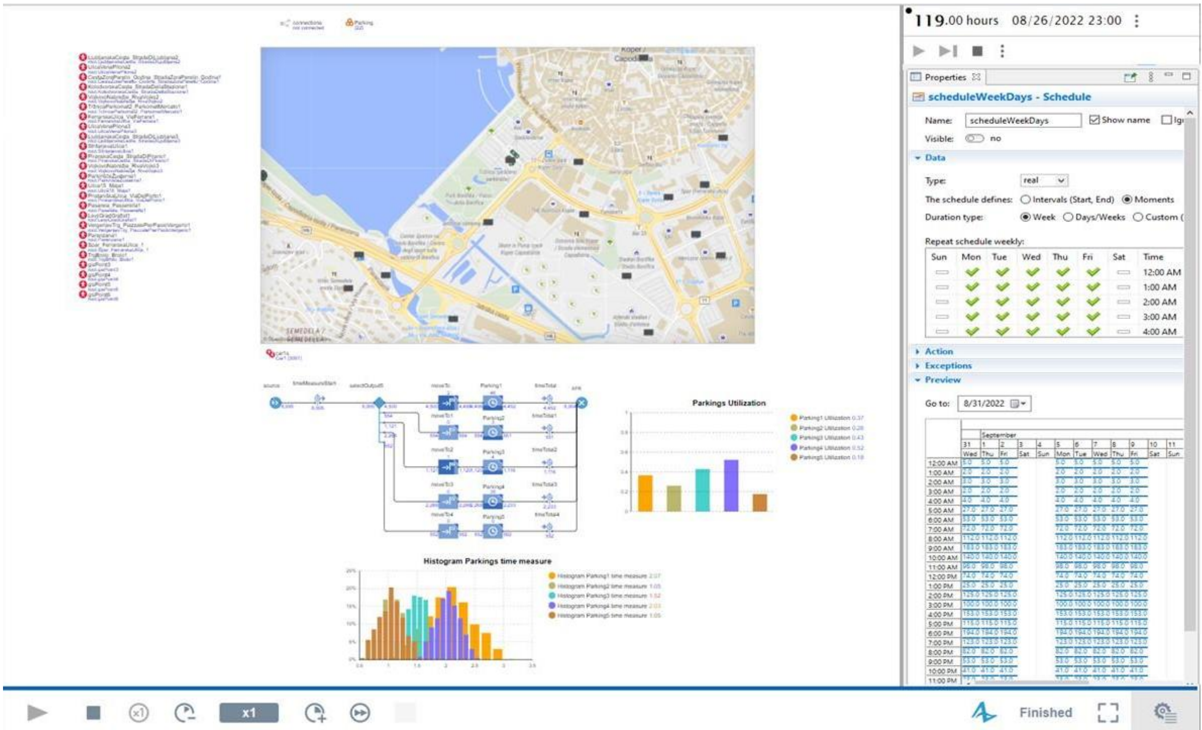

Figure 62: Scenario of parking lots on weekdays

5.6.2 Scenario 1: Parking Lot in Koper micro-scale behavior

This scenario searches to visualize on a micro-scale the movement of cars and time spent in the parking lot (Figure 63).

Figure 63: Parking Lot in Koper micro-scale behavior

In this scenario, an orthophoto is used as the environment for car agents. The road network is drawn with the Road Traffic Library with the exact number of parking lots (Figure 64).

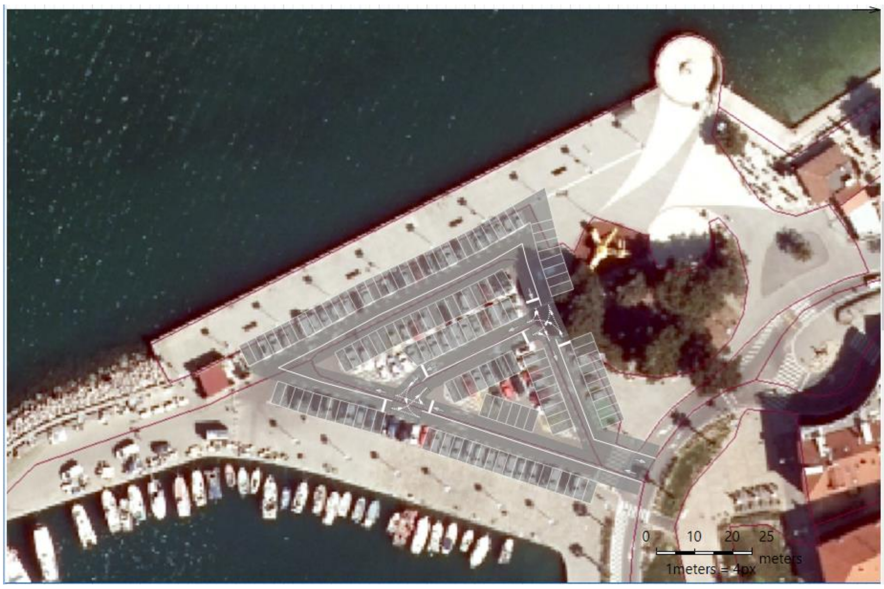

Figure 64: Environment of scenario 3: Parking Lot in Koper micro-scale behavior

Flowcharts are developed for each parking lot line to create the dynamic of (car moving to a parking lot), (selected one parking lot), and (stay a period) before leaving the parking lot (Figure 65).

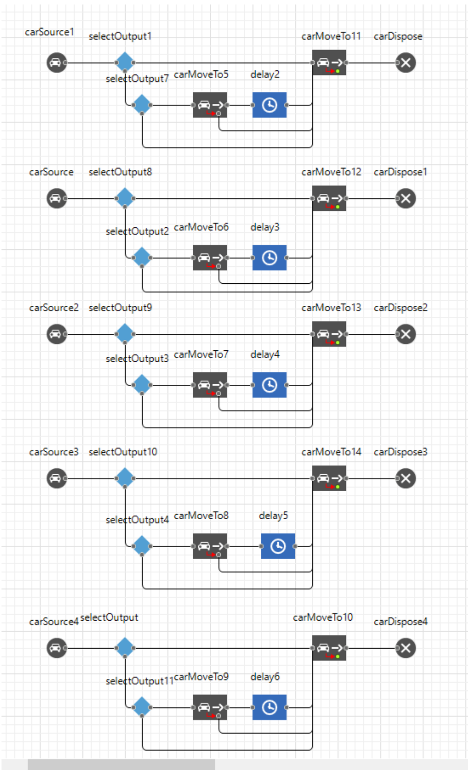

Figure 65: Flowchart simulation

Running the simulation, it is possible to see in detail the information of each block used from the road traffic library (Figure 66). Showing the detailed number of cars moving to parking lots, the time spent on them, and the number of cars moving out from parking lots.

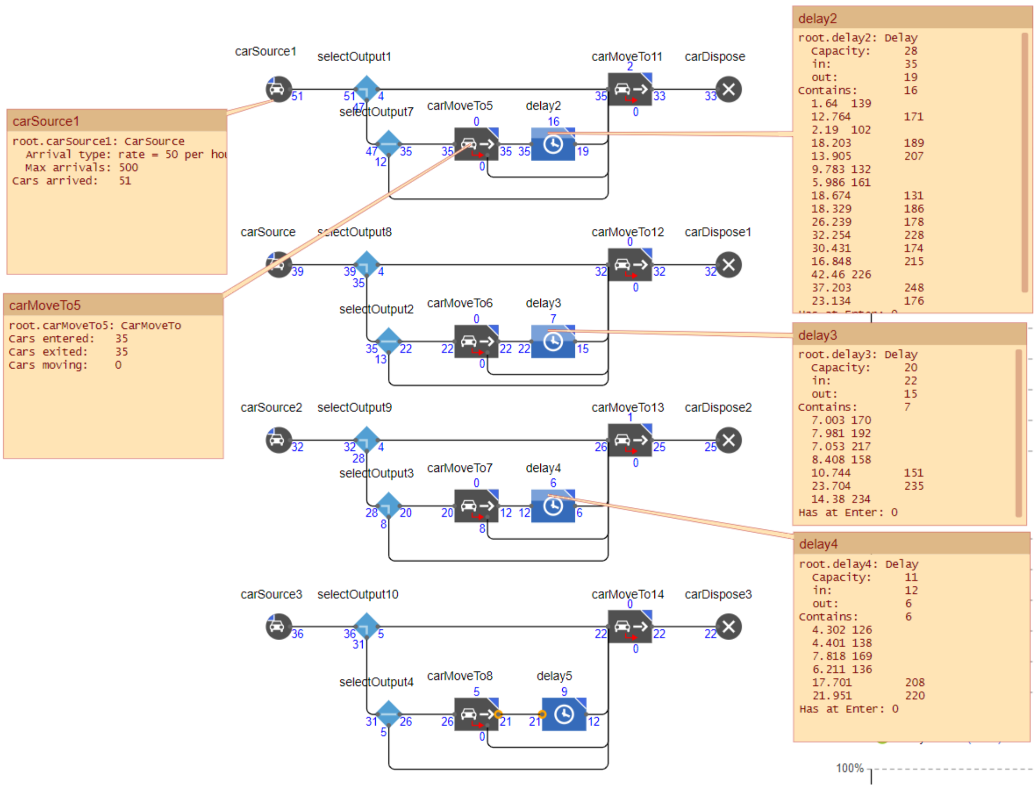

Figure 66: Flowchart simulation detail

Additionally, in this type of simulation without the GIS tool directly from Any-Logic but using an image it is possible to use a resource called Road Network Descriptor (Figure 67). This block displays traffic jams in a car density map, in this way, it is possible to see the traffic jams currently present in the simulated road network. Different colors are used gradually as cars move in the simulated space. Each color segment shows the current car density in the space. Colors change dynamically on some road segments according to the actual values. The red color is used to show roads with critical densities and the green color shows normal traffic. (The AnyLogic Company, n.d.-g).

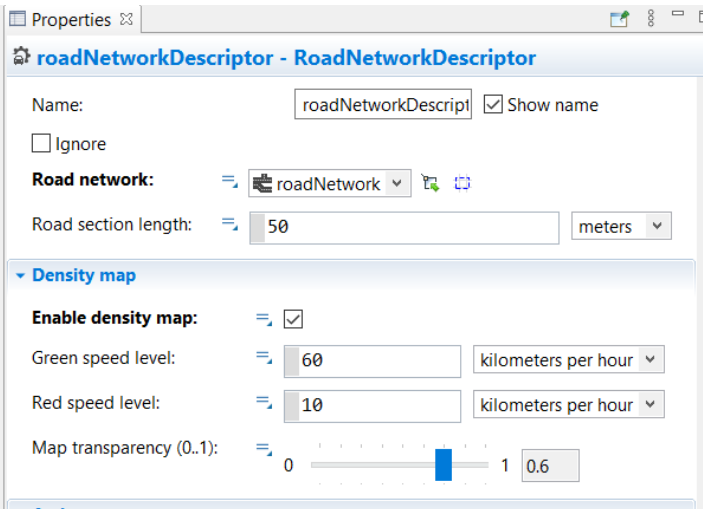

Figure 67: Road Network Descriptor properties

The resource Road Network Descriptor is used**.** This block displays traffic jams in a car density map, in this way, it is possible to see the traffic jams currently present in the simulated road network (Figure 68).

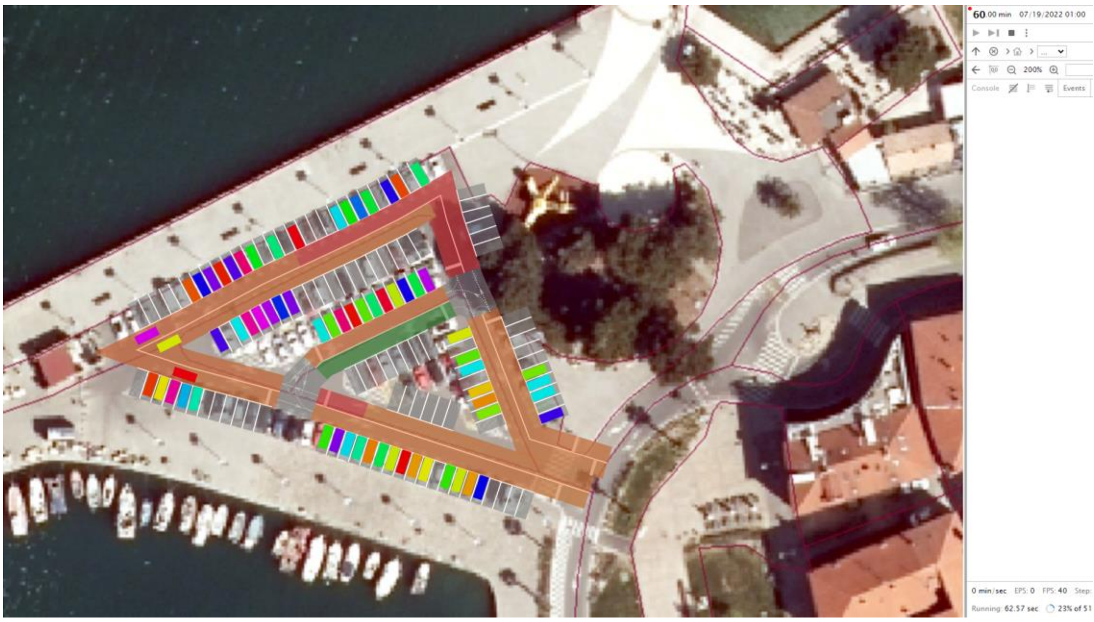

Figure 68: Road Network Descriptor

Finally, the block delay from the process modeling library is used to establish a chart of collecting utilization statics (Figure 69). In this way, it is possible to establish the min () and max (), and mean () function to get statistical values.

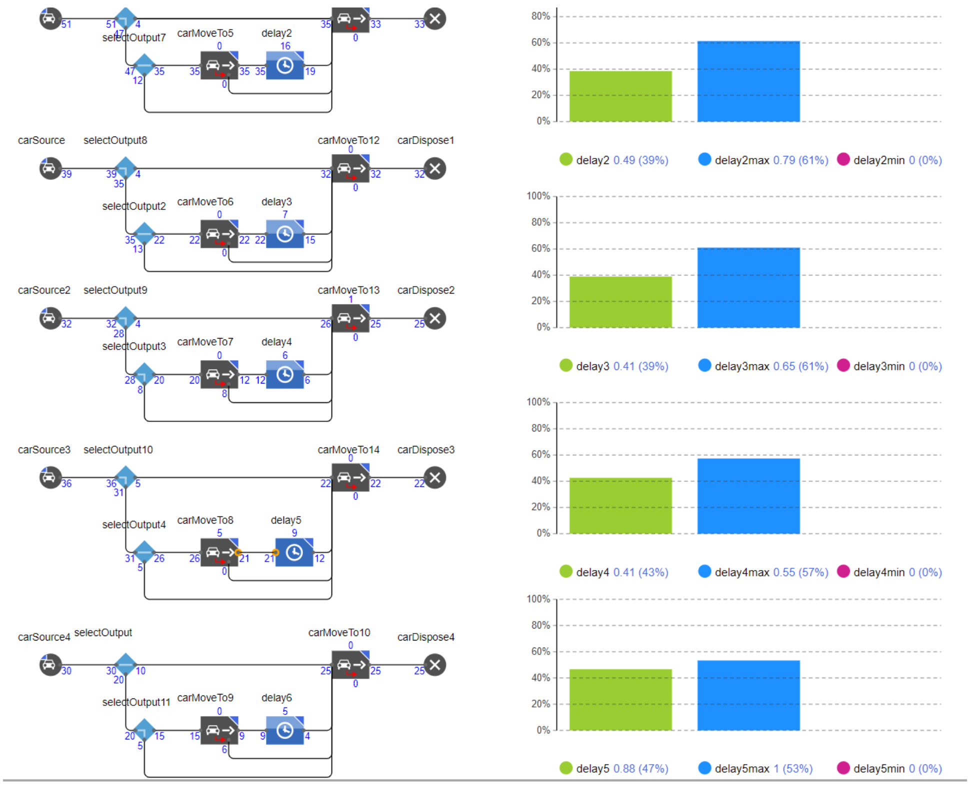

Figure 69: Chart of collecting utilization statics

5.7 Simulation combining visitor flows and parking lot dynamics

This simulation focuses on a specific area in the Koper coastline determined by the beach Območje area and one big parking lot (Parking Žusterna) (Figure 70). This scenario is important because it allows for a combination of different visitor flows in one urban space as a pedestrian, cyclist, and car flow on a weekend day. As a result, it is possible to have a detailed simulation of the agent's relations to the spatial-temporal scenario determined by a specific schedule.

Figure 70: Beach Območje area and parking lot (Parking Žusterna)

For this simulation, an image from Google Earth is inserted (Figure 71). Then, the pedestrian and road traffic library from Any-Logic was used to determine the main nodes where pedestrians, cyclists, and cars flow, according to the visualization made on-site.

Figure 71: Area determined for the simulation

The pedestrian library is used for building the workflow of pedestrians and cyclists. Agent's behaviors are limited by the schedule established by the hour rate on summer season days (8/31/2022) (Figure 72).

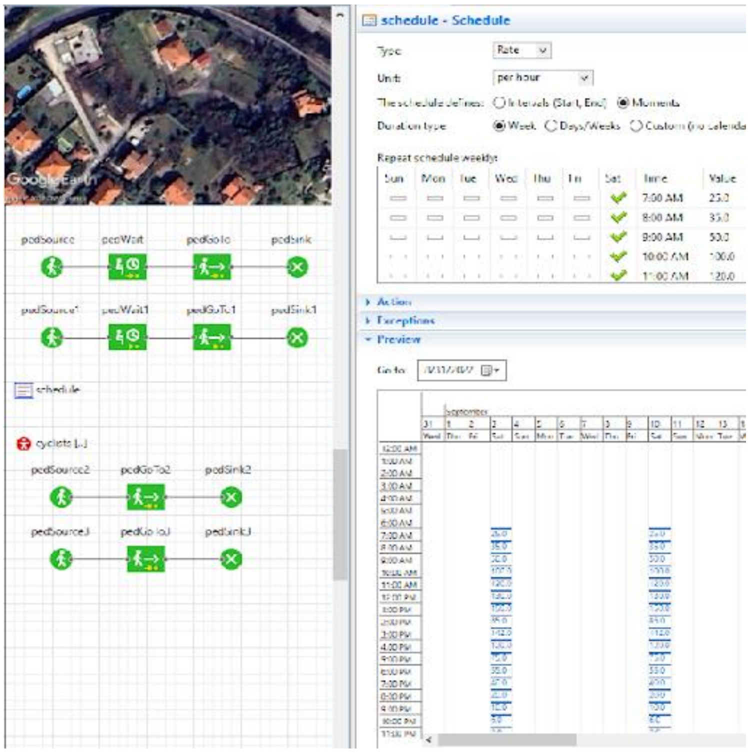

Figure 72: Pedestrian and cyclist workflow by weekend schedule.

Additionally, vehicle workflow is determined to organize their distribution into the different spaces in the whole parking lot area (Figure 73).

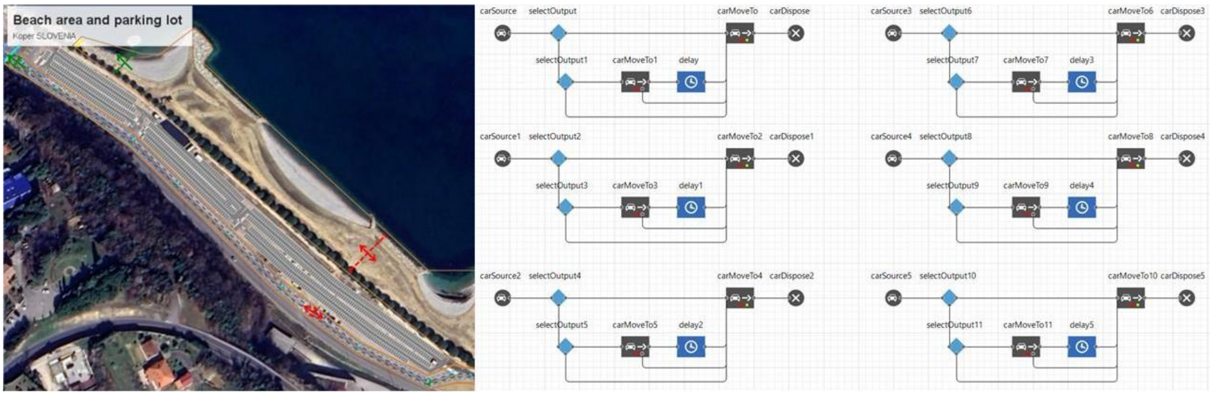

Figure 73: Area of parking lot and workflow of vehicles

Bar chart statistics about traffic and intensity from pedestrians and cyclists are determined by the simulation model time 16 hours. (Figure 74).

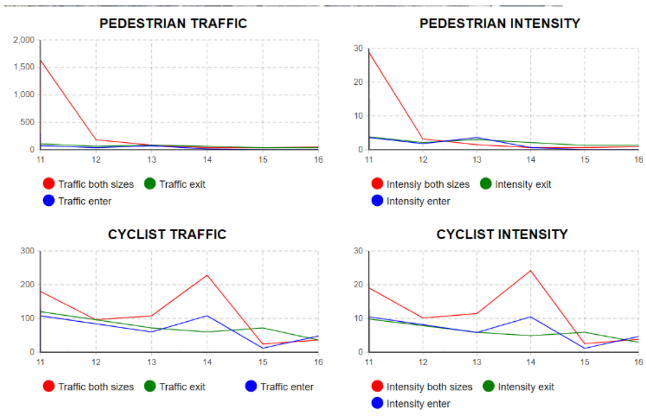

Figure 74: Pedestrian and cyclist statics results

Additionally, parking utilization statistics are established (Figure 75).

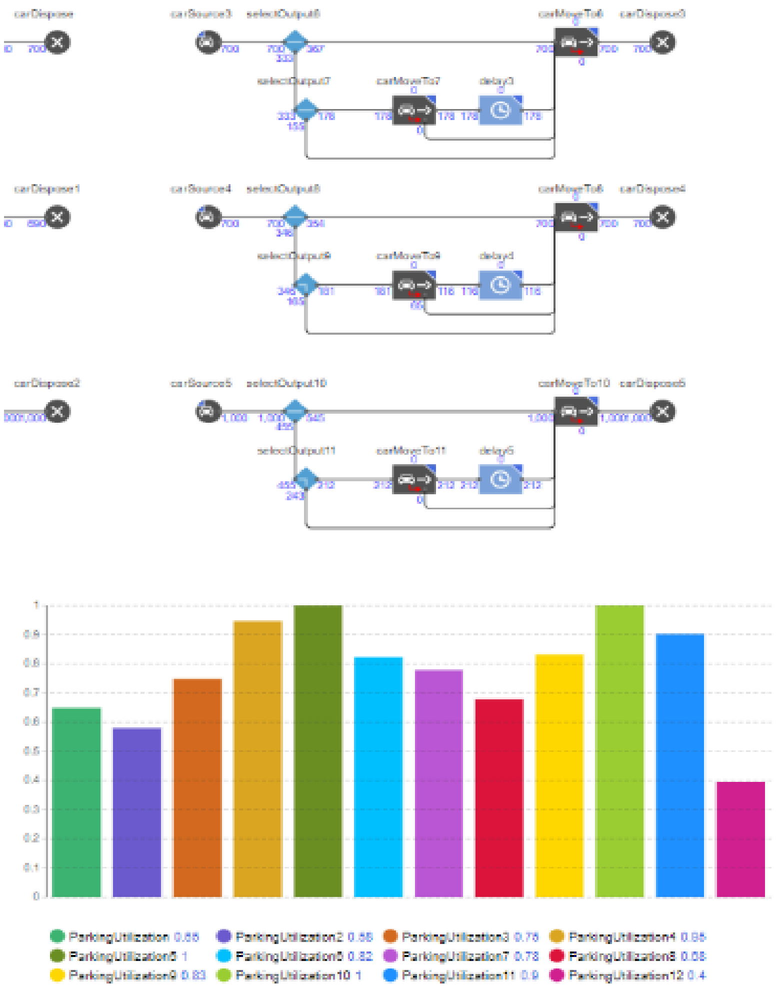

Figure 75: Parking lot utilization static results

Finally, this simulation shows the dynamic of the space about visitor flows and parking lot use (Figure 76). This is an important area where different types of visitors are related based on their mobility and period of permanence in the beach, parking lots, and cycleway. The dynamic of visitor flows on a weekend day into the summer season will produce a higher pressure on the space. More demand for parking lot spaces, infrastructures such as restaurants, or places to stay under the shadow on sunny days. All these aspects are necessary to consider when needed to establish spatial planning for coastal areas.

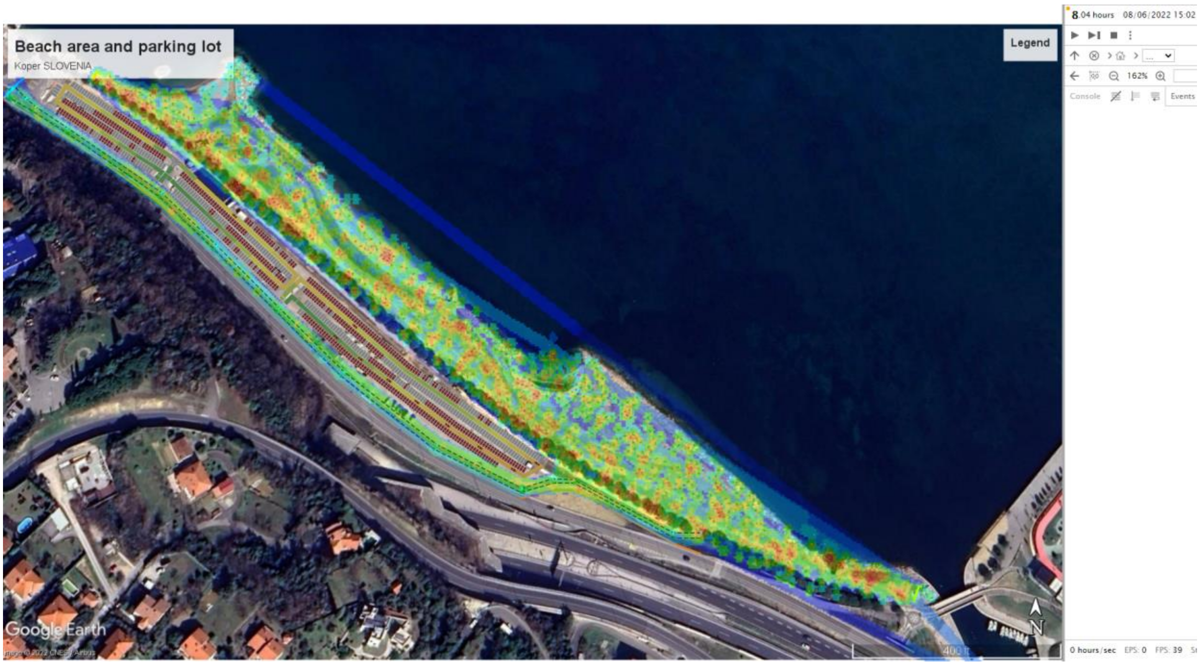

Figure 76: Simulation results in summer season at 15:00 pm

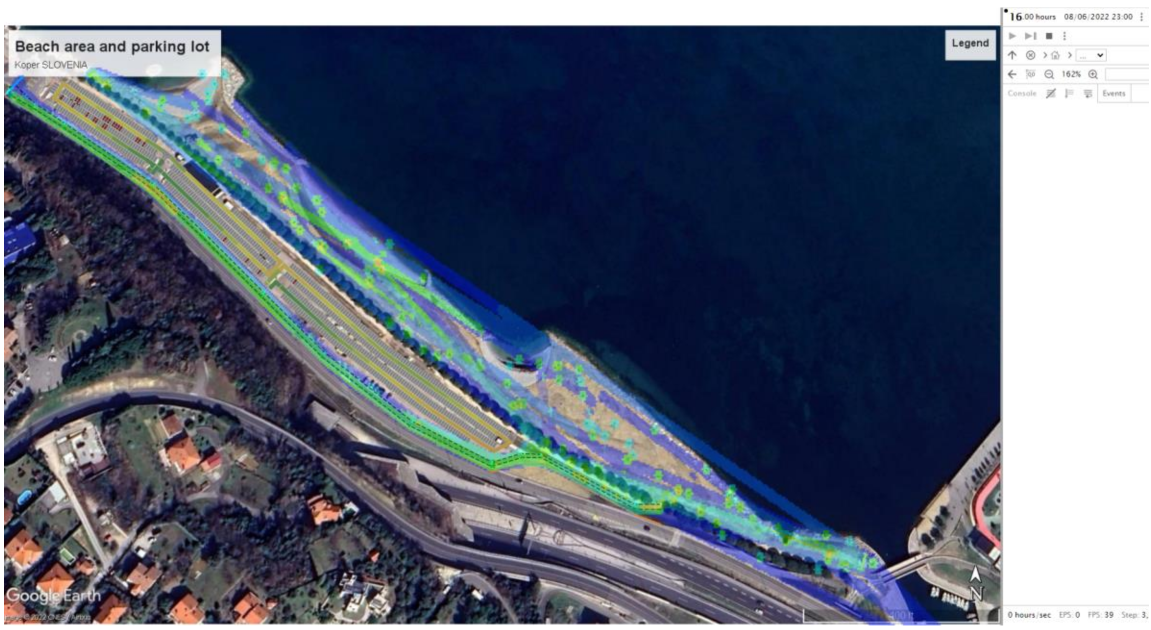

Figure 77: Simulation results in summer season at 23:00 pm

6 CONCLUSIONS

Urban Digital Twins is a digital tool that allows the development of an accurate analysis and visualization of urban dynamics. Giving as a result the possibility to understand actual and future urban scenarios to avoid future problems and maintenance between the different urban systems. The combination between space and time are variables that allow determining specific patterns and replicating them in scenarios for simulations recreating real situations or predicting future updates.

In this research, the simulations developed allowed combining the dynamic properties of different visitor flows into some specific zones of the coast area of Slovenia. The case study considered the built environment in combination with the social system with the approach of tourism flows influence. The social system is determined by human behavior regarding types of pedestrians and road traffic. As a result, different simulations replicated the actual situation of the specific place determined and at the same time allowed to change the main variables of the agent's behavior to understand future possible scenarios for the Slovenian coast area.

The different simulation models work with visitor flows and their behavior in open spaces. The software Any-Logic was used as an Agent-Based simulation modeling tool, which simulates the individual behavior of each agent. The simulation tested several alternative scenarios of visitor flow. Detailed visualization of the spatial capacity and constraints of determined areas on the Slovenian coast was possible, helping to evaluate the hot spots and their overcrowding situation concerning the pedestrian flows and road traffic flows.

The combination of Any-Logic software with the GIS tool has an application in different types of simulation. The simulation of agents into the GIS environment gives a meaningful exploration of simulations in real urban scenarios and confirms the advantage of using GIS data with the specific parameters established in the different libraries for the agents-based modeling in Any-Logic. However, the software gave some limitations when combining GIS tools with the pedestrian library. This is one of the rare limits of Any Logic which cannot natively mix GIS and pedestrian worlds.

Pedestrian and road traffic simulations helped in the analysis of hot spots in overcrowding situations. The detailed behavior visualization of agents concerning location, speeds, amounts, wait time spent, and ranges of permanence combined with density map and pedestrian flow statics were useful resources about the urban space dynamic. Thus, these results can define future specific spatial planning acts and decisions about specific areas which need to be improved concerning visitor density, new zones for infrastructure facilities, and the redistribution of road traffic and pedestrian flows.

As a final recommendation, it is necessary to consider that the use of new technologies such as Urban digital twins is important for developing smart and sustainable spatial planning projects with accurate and actualized data. Dynamic space dominated by tourist and recreational infrastructure projects generates significant effects on the urban development of the Slovenian coast. New interventions in space must be carefully planned and justified with specific data resources because they will influence the future situation of the coastal area. In the specific case of this thesis obtaining accurate data about tourism flows of pedestrians and road traffic was very limited. Municipalities need to improve more in acquiring technology tools such as sensors, and cameras among others. This will allow collecting data in real-time to develop more detailed planning projects for the future scenarios for the coast of Slovenia and in general for spatial planning in cities.

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