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SIMULATION OF PEDESTRIAN ACCESSIBILITY TO ASSESS THE SPATIAL DISTRIBUTION OF URBAN AMENITIES

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A city can be perceived as a framework for the everyday activities of its residents, whose movements create complex network patterns as consequences of their individual decisions. Given that there are apparent differences in the use of urban amenities among residents of different ages, we examined the spatial distribution of urban amenities with regard to the preferences of various age groups and the pedestrian accessibility of amenities. In this paper, we propose an algorithm for detecting the most favorable combinations for the spatial distribution of urban amenities, in order to minimize the total walking distances and maximum frequencies of pedestrians of different age groups. The proposed method focuses on the parametric interpretation of various age groups, their preferences for urban amenities, the mutual proximity between residential and non-residential areas, and crowd intensity. Since residents act as agents whose individual decisions are not predictable, we used agent-based modeling to simulate pedestrian movement in order to optimize the spatial distribution of amenities. The digital environment, which allows the parameterization of different types of data, is used for simulation performance. The simulation outcome is quantitatively presented through two criteria of pedestrian accessibility, whose mutual relationship is used to detect the final, optimized combination for the spatial distribution of amenities. This approach can assist with a better understanding of pedestrian dynamics and support pedestrian-friendly choices in urban systems. Finally, the algorithm is applied to the case study of real space in a brownfield location.

***Key words*: urban simulation, agent-based modeling (ABM), accessibility, people's preferences, urban planning.**

INTRODUCTION

Urban populations are a part of the dynamics of urban systems, and as such, have been subject to analysis in many urban studies (Benenson, 1998; Bonabeau, 2002; Crooks *et al*., 2008; Evans and Kelley, 2004; Hatch and Dragicevic, 2018; Karbovskii *et al*., 2018; Ligtenberg *et al*., 2001). In this context, a city is considered to be the framework for its inhabitants' daily activities and the buildings hosting them, where individuals create complex network patterns of movement.

There are some differences in the way residents of different ages use urban amenities (Arnberger *et al*., 2017; Tao and Cheng, 2018). For example, it is known that children do not go to the bank alone, and that adults without children will not go to kindergarten or primary school except if they work there. In this paper, we simulate the way residents visit specific amenities and, in this way, suggest improvements for their spatial distribution. Consequently, we focused on different age groups and their preferences, since different amenities attract different age groups. The paper focuses on finding the most favorable spatial combination of amenities in terms of pedestrian accessibility based on the age structure of the population. Patterns of residents' movements are not predictable by simply aggregating a particular person's behavior. That is because one person affects the behavior of others and, in aggregate, changes the route of others, thus avoiding collisions, primarily when crowds are gathered. Agent-based modeling (ABM) is used to simulate such behavior.

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Agent-based modeling is a simulation modeling tool that has generated a great deal of interest in the past decade (Huang *et al*., 2014; Lawlor and McGirr, 2017). ABM allows one to simulate the individual actions of diverse agents, measuring the resulting behavior and outcomes over time. Initially, this technique was utilized to simulate urban dynamics on a micro-scale (Benenson, 1998). Despite its many benefits as a tool for simulating the micro-diversity of dynamic systems and their emergent properties, an agent-based model only began to emerge noticeably in social simulation and geographical information science after Epstein and Axtell (1996) pointed out the possibility of its applicability to growing entire artificial cities. Some of the first agent-based simulations developed to improve decision-making processes in urban planning were models like UrbanSim (Waddell *et al*., 2003) and PUMA (Ettema *et al*., 2007). These simulations are based on the notion that agents communicate through collaboration and competition determined by a set of rules. A collection of rules defines the interaction of agents both with the environment and with each other.

The paper aims to create an algorithm to detect the most favorable combination for the spatial distribution of urban amenities, in order to minimize the total walking distances and maximum frequencies of pedestrians. The emphasis in modeling agents and determining their behavior is placed on the demographic age structure, enabling various scenarios for more favorable combinations of amenities. This algorithmic method applies to smaller urban areas, like urban blocks, but is scalable to other metropolitan and regional planning contexts. The method proposed in this paper integrates Rhinoceros and Grasshopper, with PedSim as an add-on, which provides simplified pedestrian simulation to detect the most favorable spatial distribution of urban amenities. Furthermore, the availability of amenities in an urban environment (Ardeshiri *et al*., 2018; Beames *et al*., 2018; Lee and Hong, 2013; Yamu and Frankhauser, 2016) is studied in a new way by parameterizing the residents' age structure and crowd intensity within an agent-based model for spatial simulation.

METHOD

The algorithm proposed in this paper estimates favorable positions for possible applicable amenities on selected lots based on age group preferences and accessibility. The following sections describe how these criteria are defined and how different data sets are integrated.

Age groups preferences and lists of amenities

The age structure and preferences of the residents were treated as variable parameters and used to describe interactions within the model. Firstly, it was necessary to identify age groups that have similar preferences and their needs that can be satisfied in the local urban environment. Then each age group was assigned a list of amenities they like to visit. Finally, to obtain a quantitative assessment scheme, the set of preferences assigned to each age group, in terms of urban amenities that attract them, was translated into digital data. That was achieved by using a cross-reference mechanism, which lists every file name and line number where a given named identifier occurs within the program's source tree. In this way, all possible combinations of distributions of amenities are listed.

Lists of the amenities applied to selected lots were likewise made based on previous urban analysis. Finally, these two types of lists were subjected to check matching to create the conditions for simulations and further studies.

Accessibility

We hypothesized two main factors characterizing accessibility to urban amenities: walking distance from residential buildings and crowd intensity. Walking distances were calculated as the accumulated length of routes traveled by residents from their homes to the preferred facilities in the simulation. Pedestrians are predefined to choose the best route, avoiding collisions with obstacles and other people. Since people are social beings, there are other aspects that can affect accessibility, such as their interactions with each other and various attractions and activities along the way. However, they are randomized in this study because they are not the focus of the paper.

Furthermore, the retention time of virtual pedestrians near some obstacles or other actors is not predefined and is left to the random choice of the software. So defined, pedestrians can change the route on the spot depending on the surrounding events. As a result, different walking distance values were obtained, and it was not enough to calculate the shortest distances between the residential area and amenities.

We used the frequency of pedestrians to show the crowdedness in the spatial simulation of each distribution of amenities. An analysis grid covering the entire area analyzed was used to ascertain how many persons travel through each grid cell. In this paper, the frequency is represented by the maximum number of people who visit one cell. Accessibility, through walking distances and frequencies, were expressed numerically, and the results for different distributions of amenities were later compared with each other.

Used software

To integrate ABM in the CAD environment, which is commonly used in urban planning, we used an integration of Rhinoceros, which is computer-aided design software, and its algorithmic modeling plugin – Grasshopper. Thus, a two-dimensional geometric model, which includes displaying urban morphology determined by lots and roadway patterns that define pedestrian paths, could be generated in Rhinoceros itself or imported from any other software to provide the appropriate digital environment for further analyses.

Grasshopper was used for referencing all geometric elements from Rhinoceros required for further parametric analysis, for listing all possible combinations of amenities described in section Age groups preferences and lists of amenities, and for analysis after the simulations. Simulations were performed using PedSim, a Grasshopper plugin, which made it possible to run simplified pedestrian simulations. PedSim helped agents to find the shortest route, avoiding obstacles and other agents.

ALGORITHM

The proposed algorithm estimates favorable combinations of amenities that meet the needs of different residents regarding their set of preferences and accessibility concepts expressed by reduced total walking distances and reduced maximum frequency.

Input data

The input geometry data included a 2D cadastral plan with the following elements: geometric characteristics of the residential area, lots within the non-residential area for the possible assignment of new urban amenities, roadway, parking lots, and the surrounding lots. The surrounding lots included those under previous protection, and those without permission or intention for a change of purpose. These elements were primarily defined by the shape and size of their outlines, created in CAD software, and then imported into Rhinoceros to provide the digital environment for further parametric and spatial analysis.

Input reference geometry is the identification of all relevant elements from Rhinoceros in Grasshopper. That means that all geometric data used the parameters of polyline curves, in order to be appropriately used in Grasshopper, where the parts were sorted based on previous urban analyses. Residential and non-residential lots were additionally determined by the positions of entrances to the lots. They were represented by points imported, based on the actual situation in the case study or which could be assumed for new active uses. They are the starting points for later agent-based analyses.

The surrounding lots impact the residents' movement because they represent obstacles in their path along with all the other geometric elements. In that way, the surrounding lots greatly influence the length of the walking path, thus the algorithm's ultimate result.

Specific locations within the non-residential area were marked as targets for residents' movements, and they were assigned lists of possible amenities. To determine the most favorable combination of amenities for selected non-residential lots, with regard to the level of crowdedness and walking distances for residents from the urban area, a list of potential amenities for every selected lot was created, and the preferences of different residents' groups were determined. As discussed earlier, the lists of preferable amenities presented by appropriate reference text in Grasshopper were used to make all possible combinations. Thus, they correspond to possible combinations of amenity distribution, which will be examined in further agent-based analyses.

Topographic features can significantly affect walking distances. However, simplified walking simulators adapted for use by urban planners were designed to work in a 2D environment, which means that the slopes of the walking paths could not be taken into account. For this reason, we proposed a way to introduce terrain parameters as a simple topographic configuration. First, the slope coefficient values on the slope sections of the terrain had to be provided. Then, after getting traces of travel of all agents in the simulation, we calculated the lengths of lines in the slope sections using the Trim with Region component. The actual measurements of these lines on the slope were obtained by multiplying these values by the corresponding slope coefficients. This made it possible to calculate the walking distances at the site with the slope terrain. This method can be used for more minor complex terrain configurations.

Agent-based analyses

Considering that the needs of residents drive the demand for new amenities, in this algorithm, we used a set of agents' preferences to describe their behavior and interaction within the model. The agents are represented by four age groups: children (aged 0-14 years), youth (aged 15 to 29 years), middle-aged (30 to 64 years old), and senior residents (aged 65 years or over).

The agent groups were featured with their behavior patterns as the four most dominant groups of individuals to inhabit the urban area. The groups were divided based on statistics related to the population structure of people in the EU (Eurostat, 2017). The algorithm allows the percentage share for every group of residents selected to be applicable for disparate study areas. As indicated previously, each non-residential lot was described with a list of potential amenities, while the set of preferences was attributed to each group of residents, namely, agents. Agents in this model have the primary goal of satisfying their needs as fast as possible, that is to say, that the walking distance between their dwellings and their preferred amenities should be as short as possible. Social interactions and their duration in this study were left to random software selection because they cannot be predetermined.

On the other hand, it was necessary to consider crowds, and the frequency also had to be reduced. For these reasons, PedSim, the Grasshopper plugin, was introduced. It enables real-time simulation of pedestrian movement. In PedSim, agents move from the starting point to the destination point, following the best route, avoiding obstacles and collisions with other agents.

Using the specific type of amenity primarily depends on the individual behavior of the users, Still, it is generally agreed that ensuring good access, for example, to green spaces, can generate certain benefits for specific social groups such as children (Arnberger *et al*., 2017; La Rosaa *et al*., 2018). In most cases, when they are not at school, children mainly require easily accessible spaces with a good number of features, such as playgrounds, leisure areas, basketball courts, swimming areas, food and drink facilities, and services. On the other hand, older adults have different preferences for the social and physical aspects of urban spaces compared to other social groups, as they tend to prefer calm areas with relaxing activities (Loukaitou-Sideris *et al*., 2016). Based on this general information, it can be assumed which type of amenities will be preferred by each of the four age groups. It is important to note that our goal was not to segregate users by age groups but to introduce an additional indicator to determine preferences that often overlap.

Once the lists of potential amenities were attributed to every selected lot, the algorithm calculated all possible combinations of amenities distribution. Then one combination was chosen and applied as an environment for agent-based simulation.

On the other hand, every group of agents was provided with a set of amenities according to their preferences. After choosing a combination for the lots, agents located their preferred amenities and automatically followed the shortest route to the lots with corresponding amenities. The agents' decision-making process for choosing a facility and avoiding collisions is based on the multiple force model: target force, person repulsion, obstacle repulsion, and anticipatory collision avoidance force (McNeel Europe, 2019). Agents traveled from the starting point to their target without returning. The process ended when all combinations were analyzed.

The ability of agents to make choices based on some decision rules, such as matching demand for and the possibility of applying amenities, finding the shortest route, and avoiding collisions in the proposed model, brings agent-based models closer to human reasoning.

The conceptual flow of data between different software plugins within the proposed algorithm is presented in Figure 1.

Detecting favorable solutions

The shortest walking distance for each combination of the spatial distribution of amenities was calculated as the sum of the lengths of traces obtained for every agent individually. At the same time, the highest number of individual visits per grid cell was adopted as a relevant crowd indicator. Both of these outputs were expressed numerically, and the relationships between the variables displayed graphically. The most favorable combination is the optimum between the total distances and maximum frequency. It was calculated as the shortest Euclidian distance in which one coordinate is the normalized total distance, and the other is the normalized maximum frequency. When favorable values of frequency and the shortest distance are determined, the combination of amenities, which corresponds to the specified results, is detected as well. In this way, the most favorable variety of amenities applied in a specific urban area was discovered, aiming to satisfy residents' lists of preferences and the concept of accessibility.

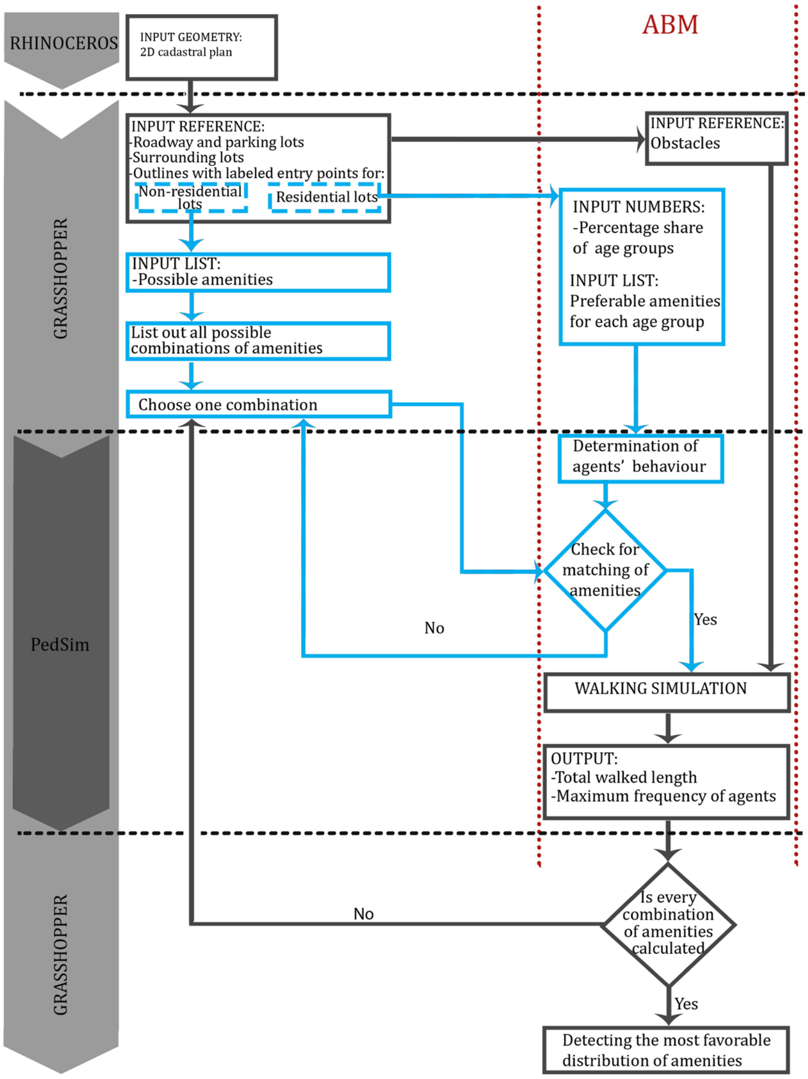

Figure 1. Flowchart of data between different plug-ins within the software
(Source: Authors, 2020)

RESULTS

Implementation of the algorithm

The algorithm presented here can be used, for example, for spaces located in an urban setting, in which the future land reuse is the subject of negotiations and planning. In that context, to test this agent-based algorithm, it was applied to the case study of Novi Sad, Serbia. We chose a brownfield site in the working zone in the west part of the city, which is well connected. The area is located near housing and accompanying urban programs (Figure 2). Within the chosen zone, there are complexes that are marked as areas of urban renewal, as well as sites that have been recently built and are well used. According to the detailed regulation plan of this part of Novi Sad (Službeni list Grada Novog Sada, 2006; Službeni list Grada Novog Sada, 2009), existing buildings in complexes that are planned for renewal can be reconstructed or upgraded.

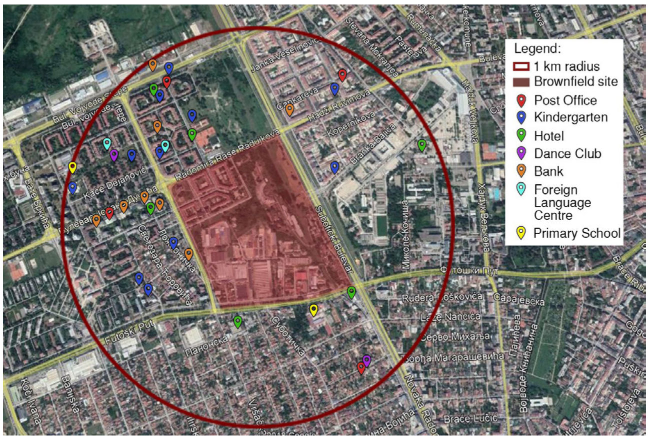

Figure 2. Area analyzed in the working zone in the west part of the City of Novi Sad within a 1km radius and locations of existing amenities (Source: Authors, 2020)

However, three buildings are under previous protection as valuable buildings in terms of the history of technical culture. The plan requires their complete physical preservation, and they must have a purely cultural purpose. Therefore, there is more flexibility in planning uses for other lots. After analyzing the amenities in the surrounding area, it was concluded that the whole region suffers from a lack of cultural programs, such as theatres, cinemas, galleries, and cultural and media centers. Accordingly, we made a list of possible amenities for each selected lot for the purposes of this research at the experimental level, taking into account the condition of the existing programs. For a more precise application of the algorithm, potential amenities in future research can be obtained based on market data and conducting a survey of residents in the area.

Afterward, the preferences of each agent group were defined by following lists of possible amenities. For the purposes of this testing, we involved only the agents from existing dwellings within the marked border of the site. According to data from the Office of Economic Development for the year 2010, the City of Novi Sad has the following age structure of the population: 14.28% children, 25.95% youth, 45.56% middle-aged, and 14.21% senior people (Profil zajednice Grada Novog Sada, 2011). Therefore, we used this information for establishing the percentage share of agent groups in the algorithm.

There are six lots at the location for which we made lists of possible amenities. Figure 3 shows the physical structure of the area studied. Lots with uses strictly defined by the plan were not considered because there was no space for significant variations in their functions. However, their programs were considered when we examined proposals for lots that are subject to change. The existing residential area was used for the spatial distribution of agents. Their boundaries were also marked as obstacles in the algorithm, along with the boundaries of other current amenities, communal facilities, green areas, and complexes planned to be kept. This is because obstacles are necessary input data to run the simulator. We also provided planned residential areas with agents to obtain possible future scenarios for using the urban space. Table 1 shows the input parameters we defined for this case study.

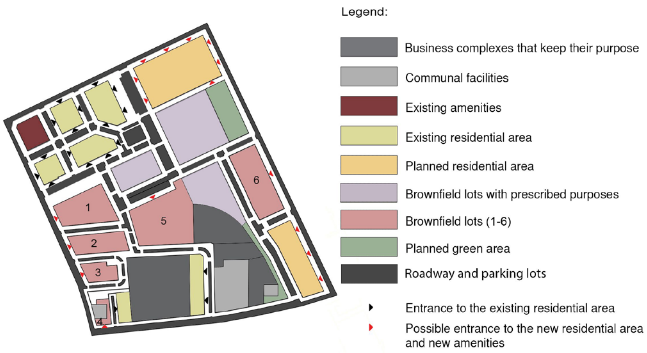

Figure 3. Spatial distribution of lots on the study site with marked entrances (Source: Authors, 2020)

Simulation results

The algorithm was applied for the study area, and 144 combinations were obtained for the spatial distribution of amenities based on age group preferences. Since 19 of them did not match the distribution of applicable amenities, 122 iterations were performed.

The percentage share of agents for all four groups was constant throughout the whole simulation. These percentages were determined based on data on the age structure of Novi Sad, as explained in the previous section. The settings for PedSim, such as body generation time of agents and probability, were set to default values during each iteration. Still, the target force (TF) and radius (R) of pedestrians varied according to the groups. For example, children were assigned a smaller body radius (R= 0.25m) than other groups (R=0.35m). At the same time, the target force was more robust for youth and middle-aged residents (TF=50) because they move faster than children and senior residents (TF=30).

Each iteration was performed for the same number of agents (500). The simulation resulted in a list of values for the total walking distances and maximum frequencies for each spatial distribution of amenities, which represent two evaluation criteria. The most favorable spatial distribution of amenities can be detected by taking into account both requirements.

Table 1. The input parameters: list of amenities for each lot analyzed and the preferred amenities (+) for every age group of agents

LOTS	APPLICABLE AMENITIES	CHILDREN	YOUTH	MIDDLE-AGED RESIDENTS	SENIOR RESIDENTS
Lot 1	Post Office	-	+	+	+
	Dance Club	+	+	+	-
	Wellness & Spa	-	+	+	-
Lot 2	Gallery	-	+	+	+
	Media Center	+	+	-	-
Lot 3	Foreign Language Center	+	+	-	-
	Cinema	+	+	+	+
Lot 4	Outdoor gym	-	+	+	-
	Chess court	-	-	-	+
	Playground	+	-	-	-
Lot 5	Kindergarten	+	-	-	-
	Park with coffee shops	+	+	+	+
Lot 6	Bank	-	+	+	+
	Restaurant	-	+	+	-

The case study in this paper was performed for flat terrain. Figure 4 shows how the lengths of the footpaths can be obtained in the case of a simple dynamic landscape configuration. After receiving the total length of the lines (d_{total}) in the selected area, it was necessary to multiply them by the slope coefficient to obtain the length of the slope.

Figure 4. Graphic representation of agent routes throughout the area (left) and representation of trace length determination in the area with sloping terrain (right) (Source: Authors, 2020)

The final result obtained by the simulation is an iteration with the following combination of the spatial distribution of amenities: lot 1 – wellness & spa, lot 2 – media center, lot 3 – cinema, lot 4 – chess court, lot 5 – park with coffee shops and lot 6 – restaurant. The agents' frequency heatmap for this combination of the spatial distribution of amenities is shown in Figure 5.

Figure 5. Agents' frequency heatmap for the resulting combination of the spatial distribution of amenities (Source: Authors, 2020)

Figure 6 shows the values of the maximum frequency and total walking distance for combinations of the spatial distribution of amenities resulting from the simulation. These values were analyzed to show the most favorable combination. The iteration with a total walking distance of 150.055m and a maximum frequency of 14 agents per cell was chosen as the optimal solution since it had the shortest Euclidean distance. The combination of the spatial distribution of amenities corresponding to this iteration is presented above as the final result.

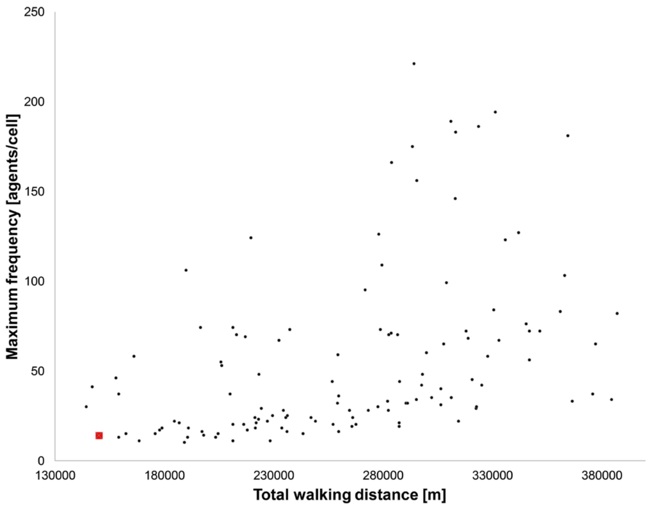

Figure 6. Total walking distances and maximum frequencies of all simulated iterations. The favorable solution is marked as a red square. (Source: Authors, 2020)

For the model simulation, we manipulated the input data for the agent groups in the zones of the planned residential area, providing different scenarios. We used extreme values for the percentage share of the agent groups for the future residential area to show a clear difference between the outcomes. Here, by assigning a percentage share of the agent groups that differs from the percentage share in the existing residential area, the algorithm gave different combinations, as explained below.

Table 2 shows the results of four different scenarios by setting one of the agent groups as dominant in the future residential area. In contrast, for the existing residential area earlier determined, the age structure characteristics for the city of Novi Sad were used. As a result, the percentage share of age groups varied, while the other input data were the same in each scenario. The first scenario shows the simulation result when the number of senior residents is prevalent in the future residential area. In contrast, the accent is put on middle-aged residents, youth, and children in the remaining scenarios. The algorithm for each scenario calculated the total walking distance for agents to their preferable amenities and the frequency of those walks. As a result, we obtained four favorable combinations of spatial distributions of urban contents for the locations with regard to both of these criteria. These different outcomes point out the importance of the age groups' participation in the spatial distribution of urban amenities, which is in the domain of potentially providing increased accessibility and walkability in the study area.

Table 2. Results for different scenarios of the simulations with a variation in the percentage share of the agents' groups in the future residential area

SCENARIO	AGE STRUCTURE IN FUTURE RESIDENTIAL AREA	ALGORITHM RESULT	DISTRIBUTION OF AMENITIES
1	90% senior residents	Combination No. 50	1. Dance Club
			2. Gallery
			3. Foreign Language Center
			4. Chess court
			5. Park with coffee shops
			6. Bank
2	90% middle-aged residents	Combination No. 126	1. Wellness & Spa
			2. Media Center
			3. Foreign Language Center
			4. Chess court
			5. Park with coffee shops
			6. Restaurant
3	90% youth	Combination No. 84	1. Wellness & Spa
			2. Media Center
			3. Cinema
			4. Outdoor gym
			5. Kindergarten
			6. Restaurant
4	90% children	Combination No. 68	1. Dance Club
			2. Gallery
			3. Cinema
			4. Playground
			5. Park with coffee shops
			6. Bank

DISCUSSION

Accessibility is 'one of those common terms that everyone uses until faced with the problem of defining and measuring it' (Gould, 1969, p. 64). The history of accessibility research can be typically presented as the history of the development of particular measures such as topological features, population potential, or space-time (Weber, 2006). The main accessibility measures can be grouped into two categories: location models and space-time (ST) measures. Location models have long been used and are still the most popular method used in accessibility assessment (Kwan, 1998; Kwan *et al*., 2003). Space-time (ST) measures were proposed to overcome the limitations of location models, such as restrictions resulting from their assumptions about origins and destinations (Kwan *et al*., 2003; Pirie, 1979) and the lack of consideration for space-time constraints and temporal variations (Kwan *et al*., 2003; Pirie, 1979). Neutens *et al*. (2010) expanded Kwan's (1998) comparative research, showing that there is a distinction between the results of assessing accessibility using space-time measures and those using geographic measures. The authors further found a substantial distinction between the results obtained using different ST measures (Neutens *et al*., 2010).

In recent years, significant advances have been made in measuring and calibrating indicators, taking advantage of new data sources, and the development of web platforms and GIS algorithms with regard to different transport modes and variations throughout the day (Geurs and Östh, 2016). However, although these new measures have transcended location models that are limited to measuring travel distance and time, it is generally destination-based geographic indicators that use GIS-based analyses and hardly consider the different preferences of local communities.

Zondag and Pieters (2005) claimed that the use of public facilities cannot be isolated from perceived accessibility, emphasizing that each individual or household has their own perception of access to urban facilities such as parks. Subjective measures are important because the tendency or willingness to act or avoid action is the result of a collective assessment according to the attributes of the object, based on prior knowledge or information (Back and Parks, 2003).

So far, complete knowledge about perceived accessibility – a notion that represents the subjective nature of the accessibility concept – is lacking. For example, when it comes to the use of parks, Byrne *et al*. (2009) found that easier access was a key reason for people's decision to use local parks, rather than large national parks. Therefore, there is a need to develop a more complete understanding of accessibility from an individual perceptual level. How the physical or non-physical construction of accessibility can affect people's perception of accessibility and ultimately their behavior should be explored. Such efforts will significantly contribute to the development of a meaningful accessibility index that can represent the subjective nature of accessibility, which is essential for facilitating decision-making in planning in order to improve the quality of urban life.

Given that previous studies have shown low agreement between perceived and geographic accessibility measures (Gebel *et al*., 2011), this paper is a step forward in bridging the gap between them. Unlike recent studies (Tiznado-Aitken *et al*., 2021) that have used a level of service (LOS) in an attempt to overcome this problem, and considered accessibility on a larger urban and regional scale as well as public transportation, this study is oriented towards pedestrian traffic and smaller urban areas, with a focus on the behavior of residents. This paper has taken a step towards a more sophisticated approach to overcoming the problem of discrepancies between perceived and objectively assessed accessibility attributes.

The use of ABM in this study stems from the understanding that human decision-making plays a major role in the process of spatial change and must be an essential part of the framework of the proposed model. There are several studies that have applied the ABM paradigm to the field of urbanism, within which two directions of research can be identified (Benenson, 1998; Ligtenberg *et al*., 2001). The first focuses on the so-called bottom-up process in which agents are perceived as individuals who choose locations according to their individual preferences. This direction is most often applied to the dynamics of land use. The second line of research attempts to understand the conflict of interest between the various actors involved in the planning process. Here, land use is seen as a mixture of bottom-up and top-down processes in which rules and conflicts define the end result. In this research, we focused on the first direction, the bottom-up approach, in order to understand and improve the concept of accessibility in terms of user preferences. In the algorithm, the accessibility of urban amenities is shown through abstract implementations of agent activities that aim at a more generalized framework of human spatial behavior, but still derive from the typical behaviors of different age groups.

Although the algorithm was applied to a hypothetical environment and therefore could not be fully validated against real-world data, it was nevertheless tested and found to work consistently and provide appropriate outputs consistent with expected results and inputs. The subjective nature of accessibility remains an open discussion: while most authors support that it can be measured on physical grounds, such as distance and travel time, which are universal references, our research findings suggest the need to consider human preferences for decisions on the use of space.

CONCLUSION

The approach presented in this paper shows that ABM simulations can increase pedestrian accessibility for different age groups, by optimizing the spatial disposition of urban amenities. Clarifying the concept of accessibility is an essential prerequisite for any assessment to support sustainable and citizen-friendly planning choices in the urban environment. Spatial simulations can provide informative assistance for urban planners and policy analysts for the purpose of evaluating the consequences of specific planning strategies.

Therefore, this paper proposes an algorithm that can give practical recommendations in terms of accessibility. It helps to minimize the walking distances and maximum frequencies in an urban environment regarding the spatial distribution of urban amenities. Furthermore, the algorithm presented in this article can be considered as a tool, which can give us new empirical insights on the possibilities for the influence of civil society, and thus increase the consciousness of negative and positive side effects of market-oriented planning practices. This could provide academics and policy-makers with new insights that could contribute towards strengthening public interest and civil society in urban planning.

The model presented in this paper is still at an early stage of development, and it aims to present a generalized formalization of human movement in public space. A conscious effort has been made to simplify the model's elements. This is primarily because Rhino and Grasshopper are mostly static computer-aided design programs, and as such have inherent limitations. Multi-agent motion simulations can drastically slow down iterations and thus limit the total amount of agents visualized, thereby reducing the overall realism. In addition, the system so far does not allow the grouping of family and friends. Clustering residents based on their age is one option that proved to be justified, since it showed different results in this research. There are other attributes not considered in this work, such as clustering based on gender, education, income, or other criteria, as well as introducing employees or visitors, which will be considered in further research. On the other hand, the pedestrian traffic taken into account in the simulation may differ from the actual situation due to the interference resulting from other kinds of traffic-related factors (e.g., traffic lights, car traffic).

Further research is needed to identify additional spatial behaviors and extend existing types of activities, in order to extend the scope of the model to other spatial configurations and environments. Much remains to be discovered about the more subtle aspects of behavior that influence user decision-making when choosing urban contents. The availability of very detailed data on the daily routines of households, such as a detailed panel survey of daily activities, could greatly improve our understanding of for example the complex phenomenon of accessibility to urban facilities. The possibility of using parameterization data from other areas which are not directly linked to urban planning, in this case socio-behavioral elements, provides the potential for the further interdisciplinary development of this approach. We also intend to develop additional algorithmic structures that will deal with multiple lots and amenities and more complex terrain configurations in future research.

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REFERENCES

Ardeshiri, A., Willis, K., Ardeshiri, M. (2018). Exploring preference homogeneity and heterogeneity for proximity to urban public services, *Cities,* Vol. 81, pp. 190-202. https://doi.org/10.1016/j.cities.2018.04.008

Arnberger, A., Allex, B., Eder, R., Ebenberger, M., Wanka, A., Kolland, F., Hutter, H. (2017). Elderly resident's uses of and preferences for urban green spaces during heat periods, *Urban Forestry and Urban Greening,* Vol. 21, pp. 102–115. https://doi.org/10.1016/j.ufug.2016.11.012

Back, K.-J. & Parks, S. C. (2003). A Brand Loyalty Model Involving Cognitive, Affective, and Conative Brand Loyalty and Customer Satisfaction, *Journal of Hospitality & Tourism Research*, Vol. 27, pp. 419-435. https://doi.org/10.1177/10963480030274003

Beames, A., Broekx, S., Schneidewind, U., Landuyt, D., Van Der Meulen, M., Heijungs, R. Seuntjens, P. (2018). Amenity proximity analysis for sustainable brownfield redevelopment planning, *Landscape and Urban Planning*, Vol. 171, pp. 68-79. https://doi.org/10.1016/j.landurbplan.2017.12.003

Benenson, I. (1998). Multi-agent simulations of residential dynamics in the city. *Computers, Environment and Urban Systems,* Vol. 22, No. 1, pp. 25-42. https://doi.org/10.1016/S0198-9715(98)00017-9

Bonabeau, E. (2002). Agent-based modeling: Methods and techniques for simulating human systems, *Proceedings of the National Academy of Sciences of the United States of America,* Vol. 99 (Suppl 3), pp. 7280-7287. https://doi.org/10.1073/pnas.082080899

Byrne, J., Wolch, J., Zhang, J. (2009). Planning for environmental justice in an urban national park, *Journal of Environmental Planning and Management*, Vol. 52, pp. 365-392. https://doi.org/10.1080/09640560802703256

Crooks, A., Castle, C., Batty, M. (2008). Key challenges in agent-based modelling for geo-spatial simulation. *Computers, Environment and Urban Systems,* Vol. 32, No. 6, pp. 417-430. https://doi.org/10.1016/j.compenvurbsys.2008.09.004

Epstein, J. M., Axtell, R. (1996). *Growing artificial societies: Social science from the bottom up*. Cambridge, MA: MIT Press.

Ettema, D., De Jong, K., Timmermans, H., Bakema, A. (2007). PUMA: Multi-agent modelling of urban systems. In Koomen, E., Stillwell, J. *Modelling land-use change*. Springer. Dordrecht, pp. 237-258. http://doi.org/doi:10.1007/1-4020-5648-6_14

Eurostat (2017). *Being young in Europe today - demographic trends,* Luxembourg: Eurostat [online]. http://ec.europa.eu/eurostat/statistics-explained/index.php?title=Being_young_in_Europe_today_-_demographic_trends [Accessed: 2 Jul 2018].

Evans, T. P., Kelley, H. (2004). Multi-scale analysis of a household level agent-based model of landcover change, *Journal of Environmental Management,* Vol. 72, No. 1, pp. 57-72. https://doi.org/10.1016/j.jenvman.2004.02.008

Gebel, K., Bauman, A. E. Sugiyama, T., Owen, N. (2011). Mismatch between perceived and objectively assessed neighborhood walkability attributes: prospective relationships with walking and weight gain, *Health & Place*, Vo. 17, No. 2, pp. 519-524. https://doi.org/10.1016/j.healthplace.2010.12.008

Geurs, K.T., Östh, J. (2016). Advances in the measurement of transport impedance in accessibility modelling, *European Journal of Transport and Infrastructure Research*, Vol. 16, No. 2, pp. 294-299. https://doi.org/10.18757/ejtir.2016.16.2.3138

Gould, P. R. (1969). *Spatial Diffusion (Resource Paper No. 4*). Washington, DC: Association of American Geographers.

Hatch, K., Dragicevic, S. (2018). Urban geosimulations with the Logic Scoring of Preference method for agent-based decision-making, *Habitat International,* Vol. 72, pp. 3-17. https://doi.org/10.1016/j.habitatint.2017.09.006

Huang, Q., Parker, D.C., Filatova, T., Sun, S. (2014). A Review of Urban Residential Choice Models Using Agent-Based Modeling, *Environment and Planning B: Urban Analytics and City Science,* Vol. 41, No. 4, pp. 661-689. https://doi.org/10.1068/b120043p

Karbovskii, V., Voloshin, D., Karsakov, A., Bezgodov, A., Gershenson, C. (2018). Multimodel agent-based simulation environment for mass-gatherings and pedestrian dynamics. *Future Generation Computer Systems,* Vol. 79, No. 1, pp. 155-165. https://doi.org/10.1016/j.future.2016.10.002

Kokx, A., Van Kempen, R. (2010). A fact is a fact, but perception is reality: stakeholders' perceptions on urban policies in the process of urban restructuring, *Environment and Planning C: Government and Policy*, Vol. 28, pp. 335–348. https://doi.org/10.1068/c0932

Kwan, M. P. (1998). Space-time and integral measures of individual accessibility: A comparative analysis using a point-based framework, *Geographical Analysis*, Vol. 30, pp. 191- 216. https://doi.org/10.1111/j.1538-4632.1998.tb00396.x

Kwan, M.P., Murray, A. T., O'Kelly, M. E., Tiefelsdorf, M. (2003). Recent advances in accessibility research: Representation, methodology and applications, *Journal of Geographical Systems*, Vol. 5, pp. 129-138. https://doi.org/10.1007/s101090300107 https://doi.org/10.1111/j.1538-4632.1998.tb00396.x

La Rosaa, D., Takatorib, C., Shimizub, H., Priviteraa, R. (2018). A planning framework to evaluate demands and preferences by different social groups for accessibility to urban greenspaces, *Sustainable Cities and Society,* Vol. 36, pp. 346-362. https://doi.org/10.1016/j.scs.2017.10.026

Lawlor, J. A., McGirr, S. (2017). Agent-based modeling as a tool for program design and evaluation, *Evaluation and Program Planning*, Vol. 65, pp. 131-138. https://doi.org/10.1016/j.evalprogplan.2017.08.015

Lee, G., Hong, I. (2013). Measuring spatial accessibility in the context of spatial disparity between demand and supply of urban park service, *Landscape and Urban Planning,* Vol. 119, pp. 85-90. https://doi.org/10.1016/j.landurbplan.2013.07.001

Ligtenberg, A., Bregt, A. K., Van Lammeren, R. (2001). Multi-actor-based land use modelling: Spatial planning using agents, *Landscape and Urban Planning,* Vol. 56, No. 1-2, pp. 21-33. http://doi.org/10.1016/j.jenvman.2004.02.007

Loukaitou-Sideris, A., Levy-Storms, L., Chen, L., Brozen, M. (2016). Parks for an aging population: Needs and preferences of low-income seniors in Los Angeles, *Journal of the American Planning Association*, Vol. 82, No. 3, pp. 236–251. http:// doi.org/10.1080/01944363.2016.1163238

McNeel Europe (2019). *PedSim (by Gradient12)*. Food4Rhino [online]. https://www.food4rhino.com/app/pedsim [Accessed: 26 May 2020].

Neutens, T., Schwanen, T., Witlox, F., De Maeyer, P. (2010). Equity of urban service delivery: a comparison of different accessibility measures, *Environment and Planning A*, Vol. 42, pp. 1613-1635. https://doi.org/10.1068/a4230

Pirie, G. H. (1979). Measuring accessibility: a review and proposal, *Environment and Planning A*, Vol. 11, pp. 299-312. https://doi.org/10.1068/a110299

Profil zajednice Grada Novog Sada (2011). Novi Sad: Kancelarija za lokalni ekonomski razvoj (in Serbian).

Službeni list Grada Novog Sada (br. 13/2006). *Plan detaljne regulacije dela radne zone "Zapad" u Novom Sadu* (in Serbian).

Službeni list Grada Novog Sada (br. 52/2009). *Plan detaljne regulacije stare ranžirne stanice u Novom Sadu* (in Serbian).

Tao, Z., Cheng, Y. (2018). Modelling the spatial accessibility of the elderly to healthcare services in Beijing, China. *Environment and Planning B: Urban Analytics and City Science,* Vol. 46, No. 6, pp. 1132-1147. https://doi.org/10.1177/2399808318755145

Tiznado-Aitken, I., Muñoz, J. C., Hurtubia, R. (2021). Public transport accessibility accounting for level of service and competition for urban opportunities: An equity analysis for education in Santiago de Chile, *Journal of Transport Geography*, Vol. 90, pp. 1-14. https://doi.org/10.1016/j.jtrangeo.2020.102919

Waddell, P., Borning, A., Noth, M., Freier, N., Becke, M., Ulfarsson, G. (2003). Microsimulation of urban development and location choices: Design and implementation of UrbanSim, *Networks and Spatial Economics*, Vol. 3, No. 1, pp. 43-67. https://doi.org/10.1023/A:1022049000877

Weber, J. (2006). Reflections on the future of accessibility, *Journal of Transport Geography*, Vol. 14, pp. 399-400. https://doi.org/10.1016/j.jtrangeo.2006.06.005

Yamu, C., Frankhauser, P. (2016). Spatial accessibility to amenities, natural areas and urban green spaces: using a multiscale, multifractal simulation model for managing urban sprawl, *Environment and Planning B: Urban Analytics and City Science*, Vol. 42, No. 6, pp. 1054-1078. https://doi.org/10.1068/b130171p

Zondag, B., Pieters, M. (2005). Influence of accessibility on residential location choice, *Transportation Research Record*, Vol. 1902, pp. 63-70. https://doi.org/10.1177/0361198105190200108

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