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ENSURING SUSTAINABLE URBAN PLANNING WITH THE HELP OF PARAMETRIC DESIGN TOOLS

ABSTRACT

This research aims to explore and answer the question of what sustainable urban patterns are and how a computer can help urbanists generate a range of urban patterns that can be evaluated for sustainability. It does that in the case study area in Belgrade by employing the concepts of transect urbanism and parametric design. First, the research defines the concept of sustainable density and links it to the concept of urban transects to identify sustainable urban patterns. These are later used to generate evaluation-ready results through an evolutionary algorithm. The goal is to sustainably connect the areas of Zemun with the area of New Belgrade, which have different densities and morphological patterns. The generated results were evaluated using both quantitative criteria (Floor area ratio) and qualitative criteria (Granularity, Building volumes and Urban structure) to identify the most suitable computer-generated results. The two assessments used in conjunction allowed for a more rounded evaluation of the possible outcomes and a better understanding of possible scenarios and strategies for development.

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KEY WORDS

SUSTAINABLE DENSITY

SUSTAINABLE URBAN PATTERNS

BUILDING BLOCKS

PARAMETRIC DESIGN

EVOLUTIONARY GENERATION

URBAN PLANNING

URBAN GROWTH

1. INTRODUCTION

Addressing the intricate nature of sustainable urban growth (SUG) poses a significant challenge in urban planning, even though when searching through 'sustainable' literature, Carmona (2015) states that it is very hard to find clearly stated objectives translated into clear images and examples of town form, existing or proposed. However, urban density, amongst other things, plays a crucial role in ensuring it, particularly through the densification of built-up areas while protecting agricultural lands and forests. Neither too sparse nor too dense urban patterns ensure SUG. The former takes up too many resources, and the distances become longer, making people reliant on personal transport. The latter creates unliveable spaces where the diversity and the characteristics of the urban area are lost. Silva and Clarke (2022) describe the damaging effects the urban sprawl has on the environment associated with the increase in the use of private motorised transport, furthermore, low-density development occupies proportionally larger areas of land. Angel et al. (2021) emphasise the goal of densifying urban areas to mitigate the environmental impact. Cuthbert (2006) says that the most suitable term for this is 'postmodernism' or 'sustainable development'. That is why it is crucial to determine a sustainable range of urban density for SUG. This not only preserves vital natural resources but also enhances the efficiency of spatial movement within urban environments. Recognising the varied nature of urban density, Angel et al. (2021) caution against relying solely on a single criterion. Instead, a comprehensive approach to SUG integrates qualitative and quantitative data. This nuanced perspective illuminates variations in structural or morphological density (measurable density) guiding the densification process by revealing where density is highest or lowest according to specific criteria. As per Maretto (2014), urban morphology can pose as a valuable tool that connects the technological aspects of sustainable strategies with different socio-economic aspects of urban design.

Determining an adequate range of urban density patterns for SUG can be achieved in many ways. This research adopts a concept of transect zones as a systemic structured approach to defining the connection between density and sustainable urban patterns (SUP). Similar to the varied nature of urban density, the transect method defines transect types based on the amount of open space regarding the built-up space creating a progression from less built-up transect zones (T-1) to medium built-up transect zones (T-4 and T-5) to very dense built-up transect zones (T-6 and T-7). A wide selection of transect types ensures their varied and applied use in different scenarios for different goals. The transect zones T-1 to T-3 are very sparse and represent rural to suburban areas and their morphological patterns. According to Silva and Clarke (2002), these fall within the urban patterns that are very demanding in terms of infrastructure and space for expansion. On the other hand, the T-6 and T-7 transect zones are very dense and represent too dense urban patterns that based on Donnely et al. [12] are on the dangerous edge of urbanism in terms of suitable living environments. This leaves the transect zones T-4 and T-5 where the variety of building types and morphological patterns is the highest and the buildings start clearly defining the open space as per Duany and Falk (2020). They are favourable zones for pedestrians because the movement of pedestrians is optimised for everyday needs. Based on the resource inefficiency of the transect zones T-1, T-2 and T-3 and the unliveable character of the transect zones T-6 and T-7, the T-4 and T-5 transect zones are the ones that represent the best urban patterns for this research as they enable walkability and high densities that make the public functions and infrastructure economically efficient. Ewing and Clemente (2013) also found that the quality of urban design was higher in the higher-density neighbourhoods and neighbourhoods that were primarily built in the 1960s and that the three density measures – FAR, population density and block FAR – are directly and significantly related to pedestrian counts.

Consequently, these criteria identify them as the most sustainable. A parametric approach was employed to find a set of possible permutations of how different transect zones can be combined into an urban pattern. In this research, an evolutionary approach (evolutionary algorithm) was used whereby different versions of urban patterns are generated by the computer. Each version is evaluated against a fit function (set goal) and recomputed again to advance the result. Each generation of results is, therefore, closer to the set target.

Parametric design as Çalışkan (2017) defines it is the study of compositional systems by defining the relationships between the dimensions of the form - components dependent upon various parameters.

Although the parametric variation affords a vast solution space with numerous deviations retaining the notion of surprise, the designer has control over the global behaviour of the system by alternating the morphological parameters (i.e. density, intensity, and closeness) and reflecting upon the visually represented spatial composition and pattern. According to Sakamoto and Ferre (2008), designing a complex pattern using traditional methods like drawing can be difficult. Algorithm-based design methods are better suited for creating patterns with numerous elements and harmonious variations in shape. Density can be determined both quantitatively and qualitatively, meaning that measurable data, such as Floor Area Ratio (FAR) and Floor Space Index (FSI) can serve as a quantitative dataset and morphological or urban patterns can serve as a qualitative dataset because of its descriptive, interpretation-based nature. As per Makower (2014) the research aimed to achieve SUG by achieving SUPs and scale diversity, as is seen in ‘slow urbanism’, where urban blocks or in this case building blocks evolve organically over time while being constrained by a fast-track programme.

Several studies have explored the potential of parametric design tools for sustainable urban planning. As highlighted by Taleb and Musleh (2015), later Zhang and Liu (2019), these tools enable the optimization of urban design parameters to maximize sustainability, with Taleb and Musleh focusing specifically on hot climates and Zhang and Liu on dense urban environments. Additionally, Pitts (2012) and Steinø (2019) emphasize the ability of parametric design to address both social and environmental criteria simultaneously. Yang (2023) even focuses on the optimisation of the urban block design through evolutionary computation. Much research has been done in the field of densifying existing built-up areas, however, they do not include generating a range of SUPs using evolutionary algorithms in an empty urban area.

In this context, the research paper on the case of New Belgrade (NBG) aims to explore and answer two questions. Firstly, what SUPs are and secondly, how can a computer help urbanists generate a range of urban patterns that can be evaluated in terms of sustainability?

2. MATERIALS AND METHODS

2.1. Case study area

As of the latest consensus, conducted in 2022 by the Statistical Office of the Republic of Serbia, 1.681.405 residents live in the Belgrade (main capital of Serbia) metropolitan area, with Zemun (ZMN) taking up 10,6% or 177.908 residents, while New Belgrade (NBG) takes up 12,5% or 209.763 residents. Since 2002, the population of the Belgrade metropolitan area has increased by 6.7%. As per the General Urban Plan, population increase in the forthcoming period is not predicted and the city should not be expanded, the emphasis on new development should be within the city itself. The plan also states that major changes may be expected within the single-family housing sector, which indicates densification of some sort. Belgrade's municipalities are very interesting and varied in terms of their structures. Many of them are known for their modernist layout and design, while others are known for their historical importance.

The case study area (*Figure 1*) is located between the two Belgrade municipalities of NBG to the east and southeast and ZMN to the north. The area itself is called Rasadnik Bežanijska kosa. The two municipalities are complete opposites regarding their urban structure (*Figure 2*). NBG is known for its modernist design and socialist modernist architecture. It was planned to follow the principles of the modernist functionalist movement based on Corbusier's Ville Radieuse. The area is divided into building blocks, which were built up with monumental residential and public buildings. Despite criticism of the modernist neighbourhoods, there are certain aspects that in contemporary neo-liberal conditions represent positive references such as putting a lot of thought and care into providing the residents with public infrastructure such as schools, kindergartens, shops, good public transport and access to quality open and green spaces. Dividing the neighbourhood into blocks and using massive apartment complexes defines the space and gives it unique properties such as a mix of varied urban patterns with different densities. Contrary to the modernist grid-based structure of the neighbourhood of NBG is an organically grown neighbourhood of ZMN, where the main building typology used is a single-family house with a maximum of two floors, a ground floor and an attic. The need of the owners for a big yard when building a house led to building blocks being formed, where the houses are positioned on the perimeter of the block forming a circumferential pattern of buildings with their yards and open spaces being positioned inside the block, resembling residential buildings with inner courtyards.

The case study area lies between NBG and ZMN, allowing consideration of mixing two very different typological structures to create a sustainable density (SD) of the area and a transition in the urban patterns between the two seemingly very different areas.

FIGURE 1: Case study area located between New Belgrade (east) and Zemun (North)

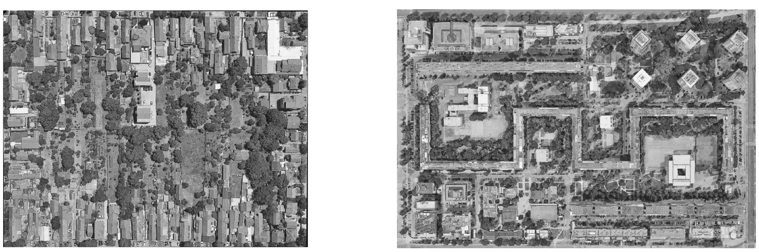


FIGURE 2: Example of a typical Zemun (left) and New Belgrade (right) building block

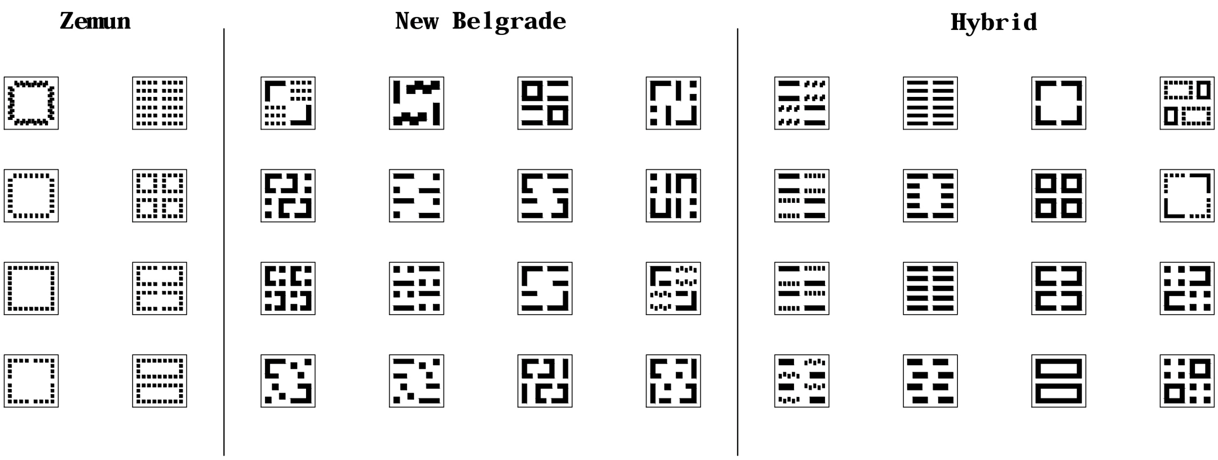
2.2. Method: synoptic survey

To link the conceptual framework of transects to the particular case of NBG, a ‘synoptic survey’ of the existing urban fabric and its classification was carried out. Sorlien et al. describe the analytical process as ‘the synoptic survey’. They describe the synoptic survey as documenting the existing area via different mediums such as photography, drawing and measuring. For these things, the area has to be sectioned into urban dissects of the same size so that an accurate analysis can be done. In this research paper, the building blocks of NBG and ZMN served as urban dissects. A set of criteria had to be established for selecting and analysing them, as Angel et al. stated, for a holistic approach, multiple criteria need to be used since one criterion approach could lead to results that in this research do not include sustainable densification and diverse urban tissue. The research focused on residential building blocks with the same shape and size. Commercial and industrial building blocks were omitted.

A graph was created to map the building blocks for clarity and identification of spatial patterns (*Figure 3*). Their FAR values were mapped on the X-axis, while their morphological patterns were mapped on the Y-axis. The research focused on the three main groups of morphological patterns, point-, line- and grid-based morphology or a mix of these. The graph helped determine into which transect zone the existing building blocks fit or correspond to. During this mapping, it was determined that most of these building blocks fall into the range of FAR values between 0.11 and 0.37. Therefore, the existing building blocks can be classified as the T-4 and the T-5 transect zones, with some building blocks that could be classified as the T-6 or the T-7. The latter were then discarded when determining a guideline for designing the meta-building blocks for the insertion into the area. The morphological patterns that emerged on the graph were also crucial for the determination of the guideline. The ZMN building blocks could be divided into two distinct groups. Both groups had a point morphological pattern with differences in their structure. The first group that was suitable for the T-4 transect zone had a circumferential building structure while the second group did not, making it denser and consequently more suitable for the T-5 transect zone. However, the NBG building blocks formed no such groups and were mainly equally distributed along the FAR values. The graph did show that there were no strictly residential building blocks with just the point, line or grid morphological patterns, which means they had a mix of point and line, a mix of point and grid, a mix of line and grid and a mix of all three morphological patterns. All of this meant that the meta-building blocks were designed based on their morphological patterns and their structures.

UPPER FIGURE
FIGURE 3: Graph mapping the building blocks, NBG at the top and ZMN at the bottom.

LOWER FIGURE
FIGURE 4: Meta-building blocks



Three groups of meta-building blocks were created to ensure a quality transition between the density of NBG and ZMN and their morphological patterns (*Figure 4*). The first group was modelled based on the building blocks of ZMN, the second was modelled based on the building blocks of NBG and the third group was created as a set of hybrid building blocks mixing the ZMN and NBG characteristics. The hybrid building blocks took the morphology of either ZMN or NBG and started forming structural patterns that correspond to the opposite part. For example, one hybrid building block could take the morphology of a building block in NBG and the circumferential structure of a building block in ZMN. These three groups provided a qualitative sample pool for the evolutionary generation of new FAR values for the case study area.

2.3. Method: evolutionary generation

Given that the meta-building blocks were designed manually and represented qualitative data, the parametric design was chosen to help quickly create multiple evaluation-ready solutions via evolutionary generation of the FAR values in the case study area. Global system control and adaptability to criteria are also the two reasons why the parametric design approach was chosen. The software used in this research were Rhinoceros 3D, Grasshopper and Galapagos. Grasshopper is a visual programming interface for Rhinoceros 3D, which is a modelling software. It enables its users to create and manage complex parametric models via visually connected components.

Galapagos is a plugin for Grasshopper that helps with optimisation and evolutionary generation, allowing users to find the best possible solutions for set problems. Sakamoto and Ferre (2008) claim that the algorithmic control of pattern-oriented compositional systems, with harmonious morphological variations, surpasses the capabilities of traditional analogue methods such as drawing.

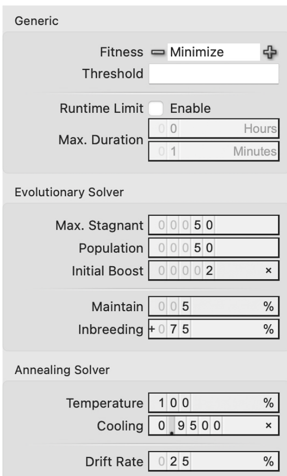


FIGURE 5:
Galapagos plug-in

Bentley and Corne (2002) investigated creative evolutionary systems and constructed a framework that served as a guideline for the evolutionary algorithm method. In the process of embryogeny, where the genotypes are mapped to phenotypes, the genotype serves as the instruction for the growth and development of the phenotype. Embryogenies offer a reduced search space, better enumeration, and the evolution of complex solutions and adaptability.

The embryogeny in this research was performed by the Galapagos plugin, which, through element iteration, determines the most optimal combination in regards to the predetermined target value. The optimisation was set by different parameters such as population size, max stagnancy, initial boost and inbreeding. The fitness parameter was set to minimise to get the result as close as possible to the fitness function (or the target value) (*Figure 5*). In short, the algorithm is used to generate new solutions by modifying genotypes (a set of initial patterns of area) comprised of the gene pool (a set of building block types - components). The genotype is decoded and, using components, the phenotype is constructed and evaluated against the fitness function (a final goal).

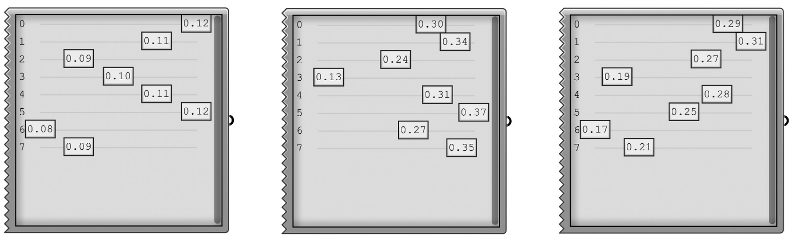


FIGURE 6: Gene pools for Zemun, hybrid and New Belgrade building blocks

The genotypes, represented by the FAR values, constructed three gene pools for each of the three groups of meta-building blocks (*Figure 6*). Each gene pool had a different range of FAR values depending on the group to which it belonged. Three different ranges ensured the separation of meta-building blocks of NBG and ZMN while simultaneously allowing the range of FAR values of the hybrid meta-building blocks to overlap with the other two gene pools, ensuring SD and a better transition between different densities of NBG and ZMN.

In an analogue manner, three fitness functions had to be determined since there were three different gene pools. The simplest fitness functions for these three different groups were the average FAR values that it needed to achieve. The fitness function for the gene pools of meta-building blocks of NBG and ZMN was determined by the average FAR of the existing building blocks, while the fitness function for the gene pool of hybrid meta-building blocks was set between the two to achieve SD and a quality transition between different densities of NBG and ZMN.

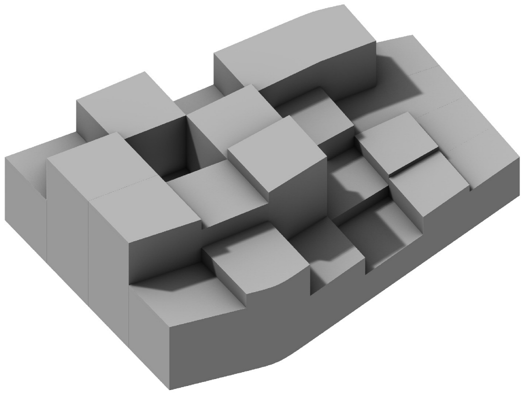


FIGURE 7: Generated FAR values extruded along the Z-axis

The ZMN value of the building block represents its FAR value and was generated by the evolutionary algorithm. That creates a visual representation of the different densities within the area before inserting meta-building blocks (*Figure 7*). Six variations were then generated that were ready for evaluation in terms of SD and the transition in different densities and morphological patterns.

3. RESULTS

3.1. Determining the criteria

Rule-based evolutionary generation of FAR values with a set target value ensured that SD was achieved in every generated solution and only the morphological pattern was left to evaluate. The morphological pattern was evaluated based on three criteria, namely (1) Granularity, (2) Building volumes and (3) Urban Structure. Each criterion had three values (Table 1); '+' (the pattern meets the criteria), 'o' (the pattern is partially meeting the criteria) and '-' (the pattern does not meet the criteria).

In the Granularity criterion, a meaningful progression of built-up tissue from the ZMN grain size to the NBG grain size was assessed. The criterion was met if a transition of morphological pattern progressed without any sudden or big changes or gaps between the neighbouring building blocks so that the density growth is linear. This is accomplished by ensuring median density values in intermediate blocks.

In the Building volumes criterion, a progression of volume (size and height of the individual buildings) from ZMN to NBG volumes was assessed. The criterion was similarly met when the transition of the morphological pattern progressed without any big changes in building volumes between the neighbouring building blocks.

Finally, the Structure criterion assessed the meaningful evolution of the urban structure of building blocks from ZMN to NBG. The criterion was met if a transition in morphological pattern without any nonsensical or sudden changes in urban structures was observed.

Description of evaluation	**+** **the result meets the criteria**	**○** **the result partially meets the criteria**	**-** **the result does not meet the criteria**
Granularity	The transition from ZMN to the NBG escalates from the finer to the coarser built-up tissue. There are no large jumps between adjacent building blocks with finer built-up tissue and adjacent building blocks with coarser built-up tissue.	The transition from ZMN to NBG partially escalates from the finer to the coarser built-up tissue. Part of the area shows appropriate, small jumps between the neighbouring building blocks, from finer to coarser built-up fabric. Part of the area shows big, inappropriate jumps between adjacent building blocks from finer to coarser built-up tissue.	The transition from ZMN to the NBG does not escalate from the finer to the coarser built-up tissue. Neighbouring building blocks show large jumps between adjacent building blocks with finer tissue and adjacent building blocks with coarser tissue.
Building volumes	The transition from ZMN to NBG escalates from low-volume building blocks to high-volume building blocks. There are no large jumps in volume between adjacent building blocks.	The transition from ZMN to NBG partially escalates from smaller to larger building volumes. Part of the area shows appropriate, small jumps between adjacent building blocks, from smaller to larger volumes of built-up tissue. Part of the area shows large, inappropriate jumps between adjacent building blocks from smaller to larger volumes of built-up tissue.	The transition from ZMN to NBG does not escalate from low-volume building blocks to high-volume building blocks. There are large jumps in volume sizes between adjacent building blocks.
Urban structure	The transition between adjacent building blocks is compositionally consistent - e.g. circumferential building blocks continue into circumferential building blocks or grids, linear into linear or grids but not circumferential into linear - buildings on the edge of adjacent building blocks do not form strong boundaries, perpendiculars, etc.	The transition between adjacent building blocks is compositionally partially consistent - part of the area is covered by building blocks where buildings on the edge of adjacent building blocks do not form strong boundaries, perpendiculars, etc. Part of the area is covered by building blocks where buildings on the edge of adjacent building blocks form strong boundaries, perpendiculars, etc.	The transition between adjacent building blocks is not compositionally consistent - e.g. perimeter to linear - buildings on the edge of adjacent building blocks form strong boundaries, perpendiculars, etc.

TABLE 1: A detailed description of the value definitions for the evaluation criteria.

3.2. Result evaluation (Table 2)

Evaluation criteria	Result A	Result B	Result C	Result D	Result E	Result F
Granularity	○	-	○	+	+	○
Building volumes	○	-	○	+	+	○
Urban structure	-	-	○	+	○	-

TABLE 2: Evaluation of generated results.

The first generated result, also result A (*Figure 8*), shows a transition in building blocks from ZMN to NBG that partially achieves two out of the three criteria and does not achieve the third criterion. A part of the area displays suitable and gradual transitions between the neighbouring building blocks from smaller built-up tissue to larger built-up tissue, while another part of the area displays big and nonsensical jumps between the two, making the granularity of the result partially achieved, and the criterion is not met fully. The gradual change of building volumes is also partially achieved. A part of the area displays meaningful transitions of the building volumes between building blocks, while another part of the area contains neighbouring building blocks with sudden jumps of building volumes between the neighbouring building blocks, making the meaningful transition of building volumes only partially achieved. While the previous two goals are partially achieved, the structure goal still needs to be achieved. The transitions in urban structures of neighbouring building blocks do not make sense and are inconsistent throughout the area. The most problematic is the transition from the second column to the fourth column of building blocks, where the structure changes from circumferential to non-circumferential and back to circumferential, continuing with the last two non-circumferential columns to the end.

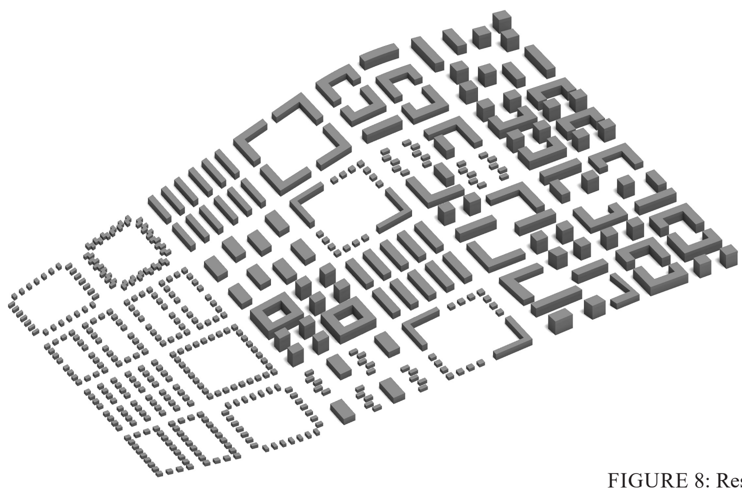


FIGURE 8: Result A

The second generated result, also result B (*Figure 9*), shows a transition from ZMN to NBG that does not achieve any of the specified criteria. The area does not show any gradual transitions between the neighbouring building blocks in terms of built-up tissue, building volumes and urban structure.

In the third and fourth columns, significant gaps in built-up tissue are visible as the building blocks progress from the second to the third column, only to revert to smaller building volumes with circumferential structures. This erratic development showcases a lack of meaningful transitions, making the overall transition lacking any resemblance of gradual change in the morphological pattern. The absence of coherence is particularly pronounced in this result, where the intended transition in morphological patterns between ZMN to NBG remains unspecific.

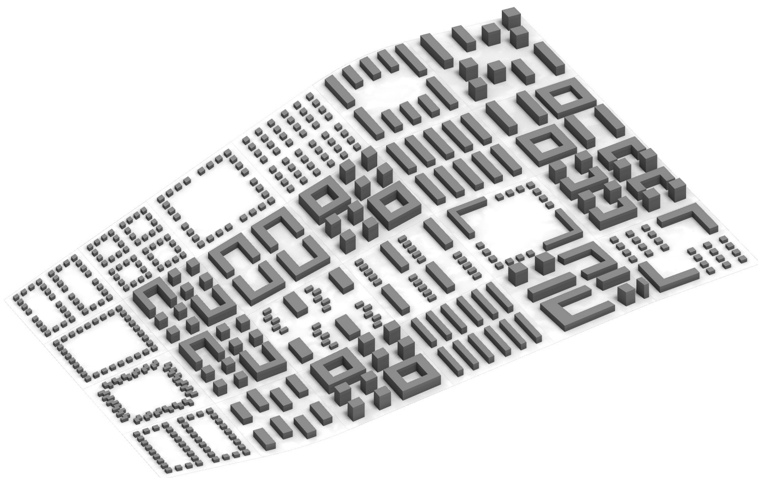


FIGURE 9: Result B

The third generated result, also result C (*Figure 10*), shows a transition from ZMN to NBG that is very close to being good in terms of all three criteria. The transition in morphological pattern from ZMN to NBG is visible in terms of granularity, building volumes, and urban structure; however, it lacks the ability to connect these three things gradually throughout the case study area. Even though a diagonal transition from the northwest corner to the southeast corner can be observed, the jumps in granularity, building volumes and urban structure are still too high. It is also visible that the low building volumes originating in ZMN reach very far into the case study area towards NBG in row one, while the higher building volumes originating in NBG reach very far into the area towards ZMN in row four. The change of granularity, building volumes and urban structure of rows two and three happens in the middle of the area, but the change in all of these three things is problematic in the second row, while the transition is good in the third row.

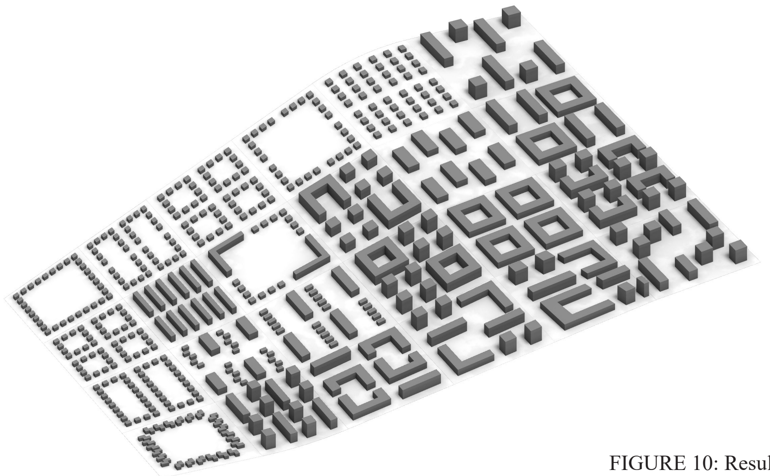


FIGURE 10: Result C

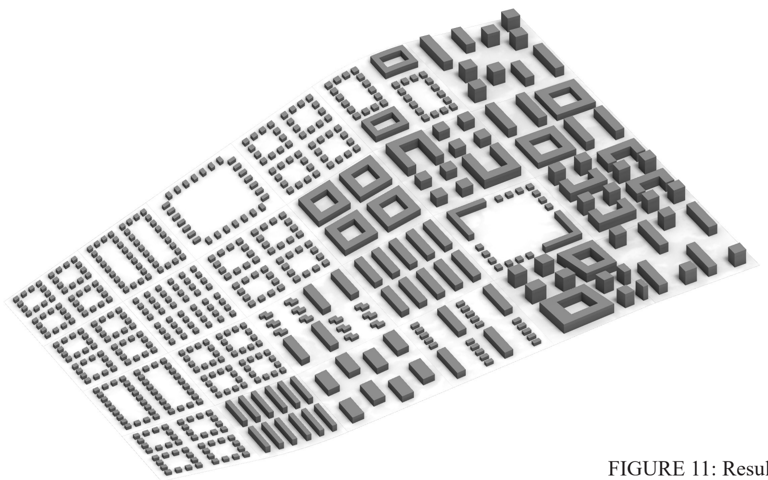


FIGURE 11: Result D

The fourth result, also result D (*Figure 11*), shows a transition from ZMN to NBG that satisfies all the criteria. Similar to the third result, the transition in morphological patterns can be observed from the northwest corner to the southeast corner. Contrary to result C, the observable transition in morphological patterns is gradual in all directions, within columns and rows themselves. The building block in the fifth column and the third row does stand out with its circumferential structure, however, it does not disturb the transition in morphological patterns as much. The transitions between granularity, building volumes and urban structure are very logical and meaningful, no sudden jumps are visible. The building blocks from the ZMN side very logically evolve into the building blocks on the NBG side.

The fifth result, also result E (*Figure 12*), shows a transition from ZMN to NBG that satisfies the criteria of granularity and building volumes while the criterion of urban structure is not entirely met. The fifth result did satisfy two out of the three criteria but with some setbacks. The transition in morphological patterns now appears to be from east to west and not so much from the northwest corner to the southeast corner. The transitions in granularity are logical and meaningful; nothing stands out in the transition of morphological patterns, and the evolution of building blocks with high granularity to building blocks with low granularity makes sense. There are no sudden jumps between two neighbouring building blocks with different granularities except for the fourth and fifth building blocks in the first row, but that change does not disturb the overall transition of morphological patterns. The volumes of the buildings also show logical evolution from the building blocks of ZMN to the building blocks of NBG. The urban structure criterion was partially met because of the building blocks three and four in the second row. Although the overall urban structure develops logically throughout the case study area, the mentioned building blocks are a setback to the overall structure of the morphological pattern in the area. If the building blocks three and four in the second row were inverted, the solution would meet all of the criteria.

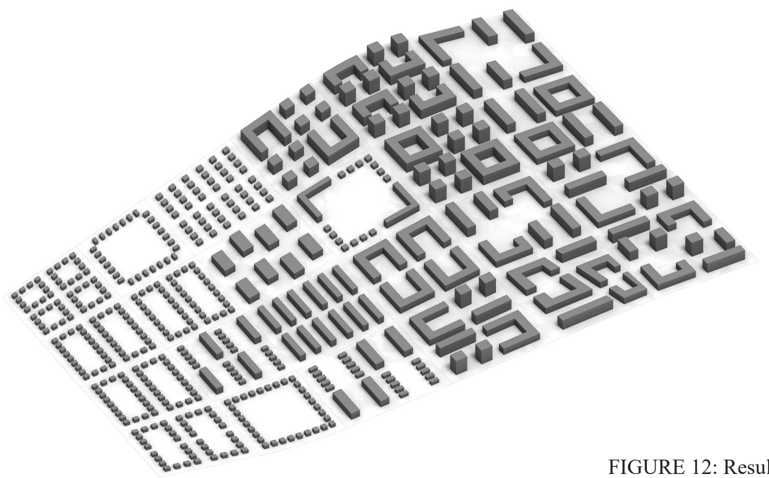


FIGURE 12: Result E

The sixth result, also result F (*Figure 13*), similar to result A, shows a transition in building blocks from ZMN to NBG that partially achieves two out of the three criteria and does not achieve the third criterion. While the evolution of the building blocks in terms of granularity can be visible, the transitions in granularity from the building blocks of ZMN to the building blocks of NBG are not always logical.

In the first row, there is a sudden jump from a building block with finer granularity to a building block with cruder granularity in building blocks three and four. A nonsensical evolution from building blocks with higher granularity to lower granularity also happens in the third row, where there is a jump to lower granularity from the second to the third building block, only for the building blocks with higher granularity to return the closer they are to NBG, where they suddenly change again from the fifth column to the sixth in the third row. On the contrary, the second and the fourth rows are not problematic in terms of granularity, and that is why the criterion was partially achieved. The same pattern could be recognised with building volumes, where rows two and four are not problematic at all, while the first and the third row show the jump in building volumes in the same places as the problems with jumps in granularity are visible. While the problematic jumps are only in two places in the case study area, they are significant enough to disturb the whole morphological transition, and the criterion of building volumes is, as a result, met partially. The criteria for urban structure were not met at all since there were noticeable changes in the structure of neighbouring building blocks in the case study area. The change of structure is not only visible in the first row in the neighbouring blocks three and four but also throughout the whole area. While the seemingly semi-logical transitions in the urban structures can be seen within the rows themselves, when looking at columns, the neighbouring building blocks seem to clash with one another throughout the whole area, disturbing the overall transition in morphological patterns, which meant that the criteria of urban structure was not met at all.

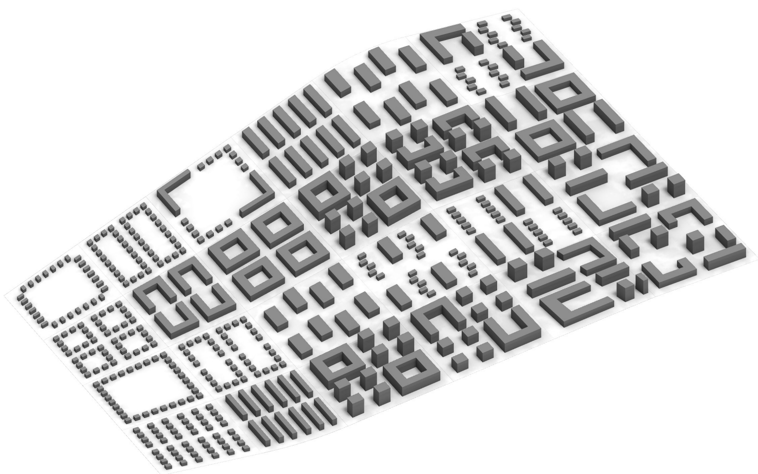


FIGURE 13: Result F

4. DISCUSSION

The evolutionary algorithm generated 6 different variations or results that were then evaluated against the set of criteria. The structure of the algorithm together with the fitness function ensured that the generated FAR values fell into the sustainable range, which was determined using the synoptic survey. The FAR values only represented the quantitative data output, while the qualitative results (the quality of transition of morphological patterns from ZMN to NBG) were evaluated by an expert. The transition of morphological patterns was evaluated against three different criteria, which were granularity, building volumes and urban patterns.

When all six variations were evaluated against set criteria, the similarities and differences between these started to emerge. Results A, C and F all partially meet the criteria of granularity and building volumes, meaning that even though a part of the area in these results shows good transition markers, a part of their areas displays sudden jumps and nonsensical transitions which makes them partially suitable. What differentiated them is that results A and F did not meet the criterion of urban structure while result C partially met it, meaning that results A and F displayed neighbouring building blocks which meant they did not show good transition markers from ZMN to NBG. Similarly to result C, result E partially met the criterion of urban structure, meaning that the overall transition was not broken, but some building blocks could be changed. Contrary to result C, result E met the criteria of granularity and building volumes, which meant that the transition of building blocks with different granularities and building volumes was logical and meaningful, creating a smooth and gradual transition from ZMN to NBG. Both results D and E met these criteria, with the difference of result D meeting the criterion of urban structure as well. Result B did not meet any of the criteria.

In conclusion, three out of six results partially met the criterion of granularity, two of the results met the criterion in its entirety, and one result did not meet the set criterion at all. Likewise, three out of six results partially met the criterion of building volumes, two results met the criterion, and one result did not. Unlike the first two criteria, three out of six results did not meet the criteria of urban structure; two results met it partially, and only one result met it fully. Considering that all of the results met the criteria for sustainable density, and only one result met all of the three qualitative criteria for a transition of morphological patterns, the best result is D, which met all of the criteria, followed by result E, which met two out of three criteria and partially met one criterion. Result C follows, which partially met all three criteria.

Results A and F, which partially met two out of three criteria and did not meet the third criterion at all, were followed by result B which is the worst result as it did not meet any of the three criteria.

After evaluating the six generated results in terms of their sustainability through quantitative and qualitative evaluation, we can now turn to the initial research question.

What are the sustainable urban patterns? Sustainable Urban Patterns (SUPs) in the research refer to gradual and logical transitions in morphological patterns from ZMN to NBG, meeting criteria such as granularity, building volumes, and urban structure. Identified through a transect-based approach, SUPs optimise density in areas with diverse building types, promoting walkability and economic efficiency. Utilising an evolutionary algorithm, these patterns balance quantitative factors like FAR with qualitative considerations, aiming to avoid unliveable spaces and achieve sustainable urban growth. Among the generated results, those fully meeting criteria (result D) are deemed most favourable, followed by those partially meeting two out of three criteria (result E). The study underscores the importance of a holistic approach to evaluating urban patterns, considering both quantitative and qualitative aspects.

Can a computer help urbanists generate a range of urban patterns that can be evaluated regarding sustainability? By using a computer and creating a generative algorithm for solution generation, it is possible to quickly generate a set of solutions that can be evaluated with given criteria. This shortens the design process significantly and offers designers a much better overview of the possible outcomes, enabling them to plan for future contingencies and understand possible scenarios and strategies for development, which would help ensure sustainable urban planning.

Parametric design allows the urban design process to be parametrically defined in several aspects, enabling a wide range of potential results (Silva, 2015). As the defining parameters can be changed, each alteration impacts the outcome, resulting in non-identical solutions as the parameters are locally defined. Further, as the visual programming languages commonly used to build generative algorithms in this context may vary in use and application, the algorithms themselves can also differ. For those reasons, the results cannot be comparable to similar research results in terms of generated parameters.

5. CONCLUSIONS

In conclusion, the research underscores the complexity of sustainable urban growth as a concept of sustainable density. It advocates for a balanced densification approach, avoiding excessively sparse or dense urban patterns. Using transect urbanism as a method, the definition of locally specific transect zones systematically connects density to the concept of sustainable urban patterns. The case study area in Belgrade examines locally defined transect zones, finding T-4 and T-5 the most optimal due to their high variety of building types and morphological patterns.

An evolutionary algorithm was used for the generation of six different urban patterns from an array of meta-building blocks. Results were then evaluated using a set of criteria (Granularity, Building volumes, and Urban structure) to understand how they mediate between and connect the areas of Zemun and New Belgrade. Two results met all of the criteria satisfactorily; three partially met them, and one did not. During the evaluation, the researchers noticed that to ensure better results, a bigger pool of meta-building blocks need to be designed with varied morphological patterns that occupy every possible FAR value, to create more varied and better results for an evaluation process. The authors conclude that the genetic algorithm is a great tool for urbanists to be able to quickly generate a set of evaluation-ready solutions, which are then used for easier predictions and a better understanding of different scenarios in the process of urban planning.

It is important to note that this research demonstrates how even a simple algorithm can be applied in the process of urban planning, making it easier and more accurate as it is based on locally defined parameters. More complex algorithms could yield better results by including additional parameters. However, it should also be noted that not every aspect of urban planning can be defined as a parameter, and this may not be the optimal approach for every scenario.

NOTES

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