A GENERATIVE DESIGN APPROACH TO URBAN SUSTAINABILITY RATING SYSTEMS DURING EARLY-STAGE PLANNING

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Abstract. Sustainability rating systems (SRS) aim to guide decision-makers in the planning process by defining clear guidelines and metrics. Nowadays, this process usually requires further tasks and the involvement of multiple professional advisors that eventually increase planning complexity and lead to lower SRS implementation. In this paper, we explore generative urban models and multi-objective optimization of SRS metrics to potentially enhance SRS use in planning processes. Furthermore, we apply this framework to a case study that has not reached its SRS planning goals due to contradicting trade-offs between municipal and stakeholder objectives. The urban model reflects the stakeholder design requirements and constraints such as the desired floor area ratio (FAR), building types, and units' number while the SRS metrics act as optimization goals. As part of the process, we automate quantitative indicators from Israel SRS '360 Neighbourhood' to use them as optimization goals and to analyse their correlation and trade-offs. Through this process, we enable a generative exploration of high-performing design iterations relative to a chosen set of SRS goals. Such a framework can enhance the integration of verified sustainability goals in the planning process, thus informing the stakeholders of their decision trade-off's concerning SRS indicators in urban development.

Keywords. Sustainability Rating Systems; Generative Design; Multi-objective optimization; Urban Modelling and Simulation; SDG 11.

1. Introduction

Urban development is becoming increasingly complex and demanding concerning rapid urbanization. Increased building activity is needed to meet the demands of anticipated population growth, adding significantly to the existing challenges of achieving sustainable urban environments. Sustainability rating systems (SRS) play a critical role in meeting these challenges and achieving UN sustainable development goals for sustainable cities and communities. This paper investigates computational optimization techniques to enhance SRS use, therefore, increasing positive impact on sustainability. Sustainability rating tools primarily serve for the evaluation of buildings. The rapid growth of cities and the challenge to assess the built urban environment concerning sustainability benchmarks have focused research on developing tools and

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assessment frameworks for urban design (Smith et al., 2016). Various methods and tools emerged in the search for a sustainable city that allows projects to display their environmental, economic, and social benefits to the local community in different planning stages of their development processes. These tools consist of frameworks with several indicators grouped into categories. While assessing and ranking the sustainability of urban developments, the tools also guide and encourage the design of sustainable informed, and high-performing communities throughout the planning process (Castanheira et al., 2014). The most established urban assessment methods are LEED-ND, BREEAM, CASBEE, and Green Star (Aspinall et al., 2012). Currently, SRS aims to help decision-makers in the planning process by defining clear benchmarks and guidelines. Yet, they also add further tasks, planning time, and the need to involve multiple professional advisors that eventually increase planning complexity and lead to lower SRS implementation (Yoffe et al., 2020).

Furthermore, During the planning process, sustainable, economic and social goals often contradict, and planning a scenario that demonstrates good trade-offs between those goals is challenging (Nagy et al., 2018). SRS metrics are built from both qualitative indicators and quantitative indicators. While qualitative indicators can be part of an administrative process or rely on expert knowledge, the quantitative indicators are analysed as numerical equations and can potentially be automated. SRS automation may save manual effort, time, and resources. In addition, it allows the integration of SRS in a generative design process as optimization goals using multi-objective optimization (MOO). Integrating LEED indicators in a generative process has been explored in the building scale (McGlashan et al., 2021). We expand the research to an urban scale that integrates municipal constraints with SRS goals. The proposed workflow can contribute to the framework of SRS due to its immediate and responsive qualities. It allows stakeholders to understand each design decision consequence, thereby enhancing informed decisions throughout urban planning evaluation, thus increasing process productivity. Another gap being addressed concerns the local SRS in Israel '360 Neighbourhood' in which each indicator is currently evaluated separately with no formal correlation. Here, we explore indicators correlation, revealing their relationships in the planning process and whether they contradict or support planning requirements. The proposed computational workflow allows the exploration of multiple iterations through high-performing design solutions relative to a chosen set of SRS goals. Applying such workflows at an urban scale enhances the integration of verified sustainability goals in the planning process and its potential correlation with the multiple stakeholders involved in the planning process.

1.1. RELATED WORK

Recent advancements in the tools available for designers pose new opportunities for measuring urban design performance. Furthermore, the increasing availability of tools and the reduction of computation time needed for analysis make performance indicators suitable for an optimization process that takes heavy computation resources (Natanian and Auer, 2020). Multiple procedural modeling techniques have been explored to assist urban design while saving time and resources (Koenig et al., 2019, Schmitt et al., 2008). Moreover, such models can be integrated with a MOO process to benefit urban design, using multiple inputs and metrics, showing correlation and analysis of the design (Wilson et al., 2019). In urban design practice, such processes have been examined, optimizing a multi-block cluster for profitability and solar energy generation while maintaining developers' requirements and design constraints (Nagy et al., 2018). Design optimization research has introduced the RBFMOpt algorithm, a novel optimizer that includes a learning algorithm that constructs surrogate models as it runs to predict simulation results (Wortmann & Fischer, 2020). At the same time, integrated computational frameworks are explored to measure urban sustainability, using machine learning predictions integrating social, environmental, and economic metrics (Koenig et al., 2021). However, Not much research has integrated urban certification sustainability systems as part of a generative framework . In landscape design, a workflow for evaluating the performance of urban landscape ecological indicators in line with sustainability rating systems has been developed. The study uses Grasshopper and Python to translate the criteria into quantitative spatial metrics and demonstrate optimized biomass measurement (Yoffe et al., 2020). At the building scale, McGlashen also automates several metrics from SRS within a design framework and demonstrates how various goals and trade-offs can be optimized by a generative design procedure that seeks to improve certification scores and reveal indicators' relationships (McGlashen et al., 2021). In this context, it is our aim to develop such implementation of SRS within a generative design system at an urban scale.

2. Methodology

This paper describes the application of automated SRS indicators as part of a multi-objective methodology at an urban scale. A case study was selected for an urban renewal project on an existing 24,000 sqm area in Holon, Israel. The project requires an expansion from 276 residential units to 1000 units and a public school of 6500 sqm.The project was in an early-stage test-fit, having two early plans made. Together with the developer, we examined possibilities to integrate the SRS indicators score while maintaining the profitability and design principles of the existing plan as defined by the developer. First, we developed a design space that could yield different design scenarios that correspond to the municipal constraints of the planning context and answer the developer's requirements. The second stage automated the SRS indicators and evaluated each design option's sustainability and profitability performance relative to the project's goals. The third phase employs the SRS metrics used as objective goals during an optimization process.

2.1 THE DESIGN SPACE MODEL

A procedural model was created to generate a broad mixture of design options based on input parameters and variables that consider the constraints and requirements of the project. The program constraints define rules determined by local municipality regulations, while program requirements are the project's programmatic goals. The chosen case study featured a program that required a thousand residential units adjusted in three

Figure 1. Previous site plan

different building typologies: three to five towers and row or 'L' type low buildings. Program constraints included a predefined site boundary, a maximum height of forty floors for towers and nine floors for low buildings, a defined density and floor area ratio (FAR) of 5.6 and an addition of 6500 sqm for a public-school area. Finally, we evaluated the developers' previous plans (Figure 1) and integrated the design guidelines and typologies in our procedural model.

2.2. PROCEDURAL GEOMETRY GENERATION PROCESS

The procedural model parameters are based on dependant relationships and rules. The project brief which outlines design constraints and municipal requirements informs the selection of the parameters. Some parameters are defined by the designer as manual settings, while others function as dynamic variables and constantly change during the optimization process (Figure 2). Rhinoceros 3D and various parametric plug-in's in the grasshopper environment are used as they allow this kind of urban procedural modeling and provide many capabilities in urban design. (Koenig et al., 2019).

Parameters list	
Manual settings	**Dynamic variables**
Number of towers	Street network
Row building max. Floor	Public area location
Floor area ratio (FAR)	Tower location
Public area sqm	Plot length
Avg. floor height	Building types
Building depth	
Building setbacks	
Apt. length	
Buildings' Setbacks	

Figure 2. Parameter's list

2.2.1 Site boundary, Street network and public-school area

The site boundary line (see fig.3a) is set as the basis for the model a nd does not change during the process. According to the design principles, ten possible street networks and public-school location scenarios are planned and stored as a list, later to be employed as variables in the optimization process. Each street width is defined depending on its location and length, eventually splitting the boundary into blocks (Figure 3b).

2.2.2. Block subdivision to plots by length

The blocks are subdivided into lots according to their length by applying the Decoding Spaces tool kit (Koenig, 2017). Using the length as a variable enables the generation of multiple lots in various sizes at each iteration (Figure 3c).

2.2.3. Subdivision of building typologies and apartments

Building typologies are defined in advance with stakeholders to include desired formal characteristics appropriate to the project. Both building and apartments are defined by their front length and depth and are manually set according to the typology design (Figure 3d). For this case study, two types of low-rise row buildings and two types of high rises buildings are defined.

2.2.4. Building's volume

Building height is an outcome of the desired density calculated as FAR and their typology coverage (Figure 3e). Each plot sqm is divided by the FAR value, which gives the number of the approximate floor for each building. Due to the nature of the design problem in this case study, low buildings height parameters derive from the manual setting parameters while the high-rise height compensate the missing floors to reach the desired FAR.

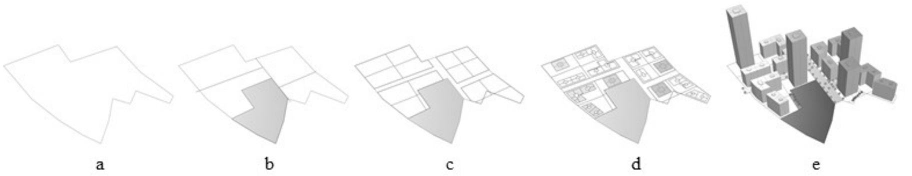

Figure 3. The urban procedural model generation stages

2.3 SRS INDICATORS AUTOMATION

In the local context of this research, we use indicator description, metrics and relative scoring from the analog Israeli evaluation tool for urban design and sustainability, '360 ° neighborhood' (ILGBC, 2019). For this case study we selected to automate five indicators based on their potential conflict with the planning requirements and their dependency on urban form (Figure 4). Moreover, the '360° neighborhood' indicator descriptions enables to categorize them by the three sustainability pillars: social, environmental, and economic (Koenig et al., 2021). While the social and environmental are from the SRS metric, the economic metric derives from the developer's programmatic requirements. For example, we aim to achieve the required density while preserving the needed "building sun rights" or achieving the developer-required towers while standing at the "affordable housing"' apartments from tower percentage requirements. Later in the process, indicators are evaluated separately and act as objectives for the MOO process.

SRS Indicators list							
Indicators	***Affordable Housing(AH)***	***Density***	***Walkable Streets(WS)***		***Buildings Sun Rights (BSR)***	***Housing Mix(HM)***	
Value threshold	a. Less than 20% of units from towers	a. 5 units per 1000 sqm	a. Less than 5m Front setback 55% to 70% = 2 70% & more = 3	b. 80% & more of 1:1.5 building street ratio	a. 4 hours sun exposure in 50% roofs surface	a. 25% of small apartments and the average unit is less than 100 sqm	b.75% three types apartments
Score	1	5	2 - 3	1	1	1	2

Figure 4. Table of the SRS chosen indicators, their value threshold and score.

2.3.1 "Affordable housing " (AH) 1 point

"Affordable housing " attempts to ensure residential units within the neighborhood that are accessible to the entire population. This metric requires that the percentage of units from 'high-rises' does not exceed 20% of the total housing units, as '360° neighborhood' considers them less affordable.

2.3.2 "Density" - 1- 5 point

"Density" promotes liveability, walkability, and transportation efficiency, reducing distance travelled (Koenig et al., 2021). In '360° neighborhood' density calculations include all planned and existing buildings within the project boundary. First, the project will be at least one and a half times larger than the minimum residential density requirements. The second requirement demands that any residential area be at a density of five dwelling units per thousand sqm, and above ten for maximum points.

2.3.3 "Walkable streets" (WS) 1-4 points.

"Walkable streets" promotes walking by providing safe, appealing, and comfortable street environments. It requires at least 55% of the block length to have a facade setback less than 5m (Figure 5). and a minimum front façade to a front plot ratio of 5.5:10 or more than 7:10. Furthermore, it requires at least 80% of all the blocks length within the project to have a minimum building-height-to-street-centreline ratio of 1:1.5 (Figure 6)

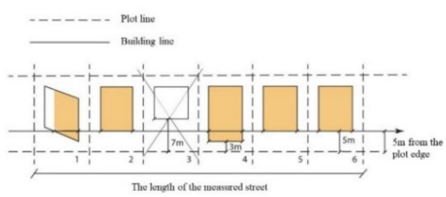

Figure 5. Setback requirement diagram from '360° neighborhood'

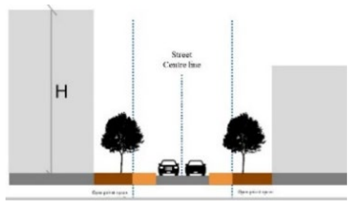

Figure 6. building-height-to-street-ratio diagram from '360° neighborhood'

2.3.4 "Buildings Sun right"(BSR) 1 point

"Buildings Sun rights" refers to channelling solar radiation to illuminate buildings and generate renewable energy. It requires that at least 90% of the buildings' roofs have 50% surface with four hours sun exposure time between 09:00-15:00 (Figure 7). The solar radiation studies were carried out using the plug-in Ladybug within Grasshopper.

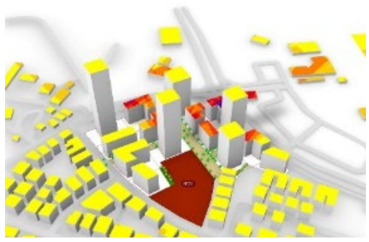

Figure 7. BSR, sun radiation analysis

2.3.5 "Housing mix" (HM)2-3 points

"Housing mix" includes apartments of different sizes and allows for a choice of accommodation from different socio-economic backgrounds and needs of populations. It requires that the average housing unit size in the project be up to 100 sqm, and at least 25% of the housing units will be small apartments 30 - 80sqm. The second requirement demands that at least 75% of the buildings in the project will include apartments of at least three different sizes, while one of the sizes must be small.

2.4 MULTI OBJECTIVE OPTIMIZATION

Whether architectural problems are well composed as MOO remains a discussion in architectural design optimization research. However, MOOs are recommended when necessary to understand trade-offs between conflicting objectives (Wortmann & Fischer, 2020). The algorithm we used in this study is the Radial Basis Function Multi-Objective Optimization (RBFMOpt) inside the "Opossum" plug-in for grasshopper. RBFMOpt is a novel, machine learning-related MOO algorithm that potentially is more efficient than evolutionary MOO algorithms like NSGA-II and HypE, popular MOO algorithms in design communities (Wortmann, 2017). The optimization trial consisted of 1000 iterations resulting in 128 possible solutions (figure 8) with an above-average SRS ranking. The optimization objectives are maximizing each indicator's points score. This way, the different points perform as weight in the optimization process.

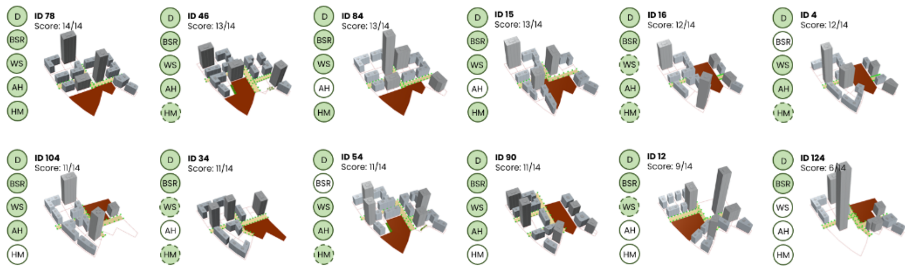

Figure 8. Possible scenarios, their SRS ranking and score. Full green dot - full indicator score, Dashed line - partial score and white dot - zero score.

3. Simulation Result and Analysis

Given that SRS has a holistic approach, and each indicator potentially can affect the optimization result, all indicators should be integrated to comprehend their behavior during the optimization process. However, the simulation aimed to test the integration of the SRS scores in a multi-objective optimization process and resulted in several behaviors indicating the experiment's success in our case study. Initially, we selected the high-ranking scenarios, compared them, and examined the relationship between their design qualities and the potential trade-off. This process highlighted recurrent patterns in several designs that can potentially become discussion topics in the planning process. For example, achieving the "Affordable housing " point was rare due to its conflict with the developer requirement of multiple towers. In our analysis, this was mitigated through the location of the public open space, which demonstrated its importance to the developer. Second, we produced a Spearman correlation matrix (figure 9) to understand the relationships between each SRS indicator to confirm our hypotheses. Moreover, the correlation matrix gave us a deeper understanding of the results as it is challenging to understand when the indicator influence comes from its given weight or its conflicting nature with the project's constraints and requirements.

As density plays a critical value in urban planning, we chose to use the FAR as an input rather than a goal in the optimization. The outcome of this choice is that all iterations answer SRS required density and the developer FAR requirements. Moreover, this makes the optimizing process clearer than using building floor numbers as input and FAR as an optimization objective. We used Spearman Rs value to show positive (blue) and negative (red) correlation, while the circle size shows if the correlation is strong, moderate, or weak. "Buildings Sun right" has a moderate correlation with the tower height resulting in returning solutions of public area located in the south of the plan and towers in the north part of the plan, possibly due to the shadow of towers affecting the solar radiation. "Walkable streets" has a moderate positive correlation with "Affordable housing" and negative on solar radiation on rooftops. Building height correlated positively with one "Housing mix" requirement and negatively with the other. Considering the requirement context, we assumed our tower typologies contained many large apartments and should be changed in future iterations. Also, some possible outcomes received identical SRS point score from different indicators prioritisation. This helps determine the influence of each indicator on the design and can be discussed in the planning process with the multiple stakeholders (Figure 10).

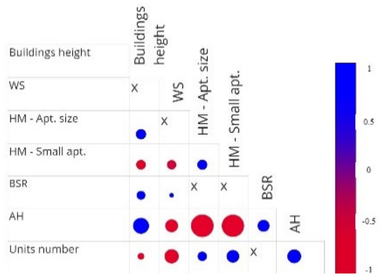

Figure 9. Spearman Rs values Correlation matrix

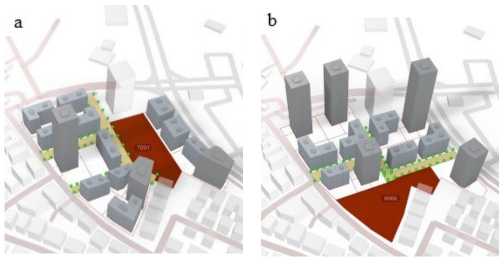

Figure 10. Design outcomes with the same SRS score prioritising different indicators. 9a AH, 9b BSR

4. Discussion and future work

There are significant challenges concerning the integration of generative models with SRS. First, the design space of the model cannot be unbiased or completely variable (Wilson et al., 2019, Nagy, 2018). While a more flexible model can generate unplanned scenarios, creating high-performing solutions requires more objectives and constraints. On the other hand, a less flexible and well-defined model will generate achievable solutions, but it could exclude possibilities desirable to some stockholders. As SRS metrics perform as guidelines in the planning process, they should be defined more as thresholds within the planning goals of the optimizing process. Therefore, one of the challenges is creating a well-structured design space to guide a successful generative process. Nonetheless, the simulation results have shown that automating SRS indicators can guide a procedural model and reveal relevant sustainable and economically scenarios for advising decision-makers. While saving planning time and manual work, this framework can lead to a higher SRS implementation in stages of early urban planning, therefore, potentially increasing positive impact on sustainability.

As described in the previous chapters, in this case study we selected to automate 5 out of 19 quantitative indicators from the local ’360° neighborhood' SRS, selecting the indicators that are conflicting with the project requirement and related to urban form. Integrating only part of SRS indicators in this process is not ideal given the holistic approach of SRS. Based on our initial results, we assume that with further developments most SRS indicators within ’360° neighborhood' could be automated and integrated into the computational framework described in this paper. However, further study will examine how this affects the optimization process, results readability, and iterations number required to reach optimal solutions. The simulation results established conclusions concerning our case study and the success of this process. Nevertheless, further evaluation is required to establish insights on both '360° neighborhood' and possibly other SRSs. Comparing indicators from numerous SRSs in a similar generative process could reveal correlated differences and relations.

5. Conclusion

This paper presented the integration of SRS's indicators in a generative design workflow at an urban scale through the case study of an urban renewal project in Israel. The proposed computational workflow allows the exploration of multiple iterations through high-performing design solutions relative to a chosen set of SRS goals. By applying such workflows on an urban scale, we enhance the integration of verified sustainability goals in the planning process and its potential correlation with the multiple stakeholders involved. A notable advantage of the framework is that it can act as a 'discussion table' in planning meetings for the evaluation of existing and future planning scenarios that are inclusive to multiple stakeholders and are driven and informed by verified sustainability rating systems. Future steps should examine further case studies and address municipal challenges concerning SRS implantation through the proposed framework within current planning processes. Generative design tools are currently transforming the designer's role from designing through plans to creating design spaces that can be explored and optimized by computational systems. Therefore, we believe that the integration of automated verified sustainability indicators within a generative process can be used as a platform to enhance future sustainability in a multi-stakeholder urban planning process.

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