

# Integrated Parametric Urban Design in Grasshopper / Rhinoceros 3D

*Demonstrated on a Master Plan in Vienna*

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*By 2050 an estimated 70 percent of the world's population will live in megacities with more than 10 million citizens (Renner 2018). This growth calls for new target-oriented, interdisciplinary methods in urban planning and design in cities to meet sustainable development targets. In response, this paper exemplifies an integrated urban design process on a master plan project in Vienna. The objective is to investigate the potential towards a holistic, digital, urban design process aimed at the development of a practical methodology for future designs. The presented urban design process includes analyses and simulation tools within Rhinoceros 3D and its plug-in Grasshopper as quality-enhancing mediums that facilitate the creative approaches in the course of the project. The increase in efficiency and variety of design variants shows a promising future for the practical suitability of this approach.*

**Keywords:** urban design, parametric modeling, urban simulation, design evaluation, environmental performance

## INTRODUCTION

A contemporary urban design process demands human-centered development where future technologies intertwine with traditional approaches to generate a sustainable, livable environment while saving time and resources. Frey defines urban design as a discipline that deals with issues that exist due to the gap in responsibility between the two disciplines of urban planning and architecture (Frey 1999). Urban design focuses mainly on the public realm, containing public streets and squares, which is created by the physical boundaries as well as private

buildings. The term public realm has broader significance than public space because it includes building facades and anything that is visible from eye level (Karssenberg 2016).

In general, the collection of this data is rather simple in comparison with the capacity of processing (Feng 2009). In contrast to traditional GIS-based planning software, the use and application of parametric modeling techniques require a knowledge of the individual parameters used and the digital data workflow (Speranza 2015). Thus, new tools allow the simulation of different qualities based on parametric

and algorithmic processes to capture the city with all its layers (Kwinter 2010).

Related research, for instance, is pursued by the Urban Strategy Playground research group at the Chair of Architecture Informatics at the Technical University of Munich [url-20]. They investigate different densification strategies as decision support for authorities with a focus on the integration of digital models, including data layers within analog planning methods. Synergies with the German company DeCoding Spaces, which employs international architects and urban planners from Weimar, are recognized [url-4]. Their ambition is an efficient architecture and urban planning with higher quality for which they develop the free software DeCoding Spaces Toolbox for Grasshopper [url-3]. Therefore, this toolbox contains various analysis and generative components that were utilized in the methodology of the paper.

The development and application of urban modeling and simulation tools are highly discussed as mentioned above. Especially with focus on specific analysis like space syntax, solar radiation, or the automated generation of urban designs using parametric definitions. But literature lacks the holistic framework of the application of different analysis methods within the urban design process.

As a consequence of this gap in the literature, the suggested integrated parametric urban design process within Rhinoceros 3D [url-2] and Grasshopper is addressed. Innovative design and parametric planning, digital tools and the experience of experts and executive planners allow the fostering of designs that can restore the quality of compromised ecosystems. A smart digital environment, supporting informative decisions and facilitating the exchange of information between stakeholders to design the built environment and public realm, is thus the key. The use of parametric modeling techniques furthermore allows generating a broad set of urban design variants that meet the criteria of sustainable development targets.

The objective is the generation and evaluation of different designs to achieve a decision base and

possible outline for architectural competitions. Furthermore, the comparison of various scenarios and the definition of appropriate analysis tools for an urban design process is included. The extent of this research focuses on the application of the methodology on a demo site in Vienna. Therefore, the developed typology aligns with cultural and common practice in Austria. Nevertheless, the information workflow can be applied in different locations all over the world with some modifications of the definitions. We argue that the further development of intelligent planning tools has a high scientific relevance due to the advancing urbanization.

## METHODOLOGY

**Software.** Rhinoceros 3D is a commercial Computer-Aided-Design (CAD) software developed by Robert McNeel & Associates that bases geometry on mathematical nurbs models. Similarly, Esri CityEngine [url-21] as GIS-based commercial software converts 2D data into intelligent 3D city models. The integrated pull-through tool allows comparison of the design proposal with other scenarios, that can be exported and used to present ideas to decision makers. On the contrary to the GIS software Esri CityEngine, Rhinoceros 3D is not meant for the handling of geo-data. Lately, it is used in various disciplines due to its high flexibility and therefore already became a state of the art in many urban design offices. Particularly the use of Grasshopper provides many capabilities for the deployment of Rhinoceros 3D in urban development.

The methodology divides the urban design process into six steps, which are arranged linearly but should be repeated in the form of feedback loops. Rhinoceros 3D and its parametric plug-in Grasshopper are set as the primary software environment based on the reasons mentioned above.

Thus the following steps of the methodology are linked together by Grasshopper, and the import and export workflow for this methodology is defined precisely. Accordingly, the data is further processed in the stand-alone software QGIS [url-13], Mapbox

Figure 1  
Methodology steps  
4-6: Urban  
Analyses, Concept  
Development and  
Design  
Development



[url-11], Envi-Met [url-14], and Unity [url-16]. The methodology steps are envisioned as follows:

1. Urban Analyses
2. Concept Development
3. Design Development
4. Simulation & Analyses
5. Design Evaluation
6. Visualization

In the beginning, the existing urban data of the City of Vienna [url-18] is imported to the Grasshopper working environment as a basis in the form of SHP files. This import procedure uses the library pyshp [url-9] and besides geometry includes the information attributes. The discussed workflow allows for a spatial analysis that provides traffic flows, the mix of uses, micro-climates, and human-centered metrics. The objective is to integrate the analysis of designs in different disciplines such as climate, usage, and spatial quality. The focus is the automation of processes such as the generation of building outlines in three-dimensional volumes and the real-time control of the gross floor area (GFA), performance, and information flow. To identify the ideal urban design options, the key parameters (geometry, accessibility, visual integration, environmental performance) are used to allow information-based decision management.

The site simulations go beyond the conventional methods belonging to traditional urban analysis and reveal the attractiveness potential and challenges of locations via evaluation of proximity to amenities. Accessibility analyses for both, the existing and the

extended street network, in which the output is defined by betweenness and closeness centrality, were carried out. Moreover, accessibility, visibility, micro-climate, solar radiation, and further parameters could thus be simultaneously combined in the workflow. What is known as performance-based computational design contains the support in spatial analysis, synthesis, and evaluation that mainly focuses on the performance during the design process (Nourian 2016). In this light, the potential to create a sustainable environment by integrated parametric urban design is promising since this workflow allows further incorporation of additional analyses and simulation.

As a result, the semi-automated generation of many informed design options in Grasshopper, the corresponding performance measures lead to a demand for an efficient design space exploration. The intent of applying semi-automated, digital tools within this process is to assist the designer intelligently. Suyoto describes the goal of parametric thinking not as a method to find a single solution but to show the different possibilities by using algorithms and modern calculation techniques (Suyoto 2015). Thus design space exploration accompanies the design process to sort, quantify, and select the best scenarios (Barrios 2011). Furthermore, selected results can be integrated into interactive online mapping and Augmented Reality (AR) presentation to facilitate further discussion between team members, stakeholders, clients, and inhabitants.

## MASTER PLAN IN VIENNA

In the following, the suggested methodology is applied to a case study in the 20th district of Vienna, the northwest station area, and integrates the cultural, social and urban qualities of the city. As an example of a Smart City, there is a broad spectrum of open data on infrastructure, demographics, and the built environment. The demonstration master plan project is a 44 hectares mixed-use neighborhood in a central location where the strategy is to replace the existing structure of the northwest station by a new development based on guidelines that were developed in a competition back in 2008 and adapted in the year 2016. The following paragraphs explain the tools and methods used in the master plan northwest station.

### 1 Urban Analyses

**Attractiveness Maps.** We argue in this paper that besides classical urban analyses such as the distribution of use, green space, and density also the proximity, variety, and density of amenities influences the urban attractiveness. The calculation of the attractiveness potential for the entire city is carried out in an analysis grid resolution of 250 meters. The amenities were divided into the categories of public transport, green areas, local supply, social infrastructure, and cultural facilities to reflect the overall attractiveness as well as the individual groups. The distance to all amenities across the city, the distance to the next, the number of amenities within walking distance and the resulting attractiveness of a given point were calculated for each grid center. A mere calculation of the nearest point would not be meaningful, as diversity and number of facilities are also essential factors for the supply.

The need for different amenities depends strongly on cultural and personal aspects. Therefore a parametric model was created in Grasshopper to make the weighting of individual groups variable. By user interface, personalized attractiveness cards can be created automatically. This flexibility forms the potential in the use of participative processes

with citizens as well as for the transfer of this attractiveness calculation to other cultures and countries. Points of Interest (POI) from OpenStreetMap and Open Government Vienna are used for the calculation. The availability and accuracy of POIs vary greatly and needs to be carefully checked to achieve a meaningful analysis.



Figure 2  
These graphs show the attractiveness of the location based on spatial analyses in relation to the proximity to amenities in public transport, educational institutions, local supply and culture

The weighted attractiveness map shown is based on values from the survey conducted by Köhler in Dresden (Köhler 2012). He examined the priority of the distance for different amenities for different environments, which are considered simplified on average for these maps. To illustrate the attractiveness values for each grid point, the results are normalized from 0-1, with a high number being positive. In the colored representation, red color means a high, calculated attractiveness for this point. Consequently, the results



of these attractiveness values strongly depend on the quality of the input POI. Furthermore, these attractiveness maps reflect only the local supply aspect and could be extended to include other features such as crime and socio-economic characteristics of the population.

**Network Analysis.** Furthermore, the analysis of space syntax was executed on the existing and planned street network to compare the impact on centrality and closeness results. For the analysis, the network analysis Components of the DeCoding Spaces Toolbox were applied to the street graph geometries of Open Data Vienna. As a result of these studies, the connectivity of the scenarios and block layouts could be evaluated.

## **2 Concept Development**

The integration of a new design in an existing urban structure is challenging due to the consideration of existing streets, blocks, and nodes. Therefore, the Magistrat 21 of the City of Vienna provided the official master plan competition outline of the year 2007 for this development territory, won by the Swiss architect ENF in the year 2008. This vision guideline includes the space requirements for the use-mix that is dominated by housing with a 70 percent share. The master plan layout proposed in 2008 is used as the basis for one scenario and further evaluated.

## **3 Design Development**

Design exploration draws on the design ideas that emerged in the first phases of the design process, which arise from the parametric models in variations of the generic and geometric components. This method is particularly useful at the beginning when the formal and geometric configuration has not yet been decided. At this point, the parametric model allows a high degree of flexibility (Barrios 2011). A review of the conventional building typologies led to the development of this morphology and represented the standard practice in Vienna and Austria in general. At the start of design development, various residential typologies are tested for their perfor-

mance in terms of solar radiation, pedestrian comfort, outdoor visibility, and optical integration in the neighborhood.

**Residential Typology.** This typology definition generates an urban residential block layout and supposed to be applied on a property outline while offering several parameters to create the geometry. This outline can be further divided into different parcels by setting the dimension and distance between the new parcels [parcel\_dimension] [distance\_parcel]. These parcels form a subdivision of the property outline and are the geometric input for the next step: creating the building outlines of the typology.

The main input parameters are the offset of the buildings to the surrounded street [street\_offset], the building depth [building\_depth], the position of openings and building splits per block side [split\_1-3], the opening width of the gap [gap\_width] and a threshold of cutting off short pieces of the buildings [cut\_off].

A self-developed component-cluster generates the building outlines, calculates the area per parcel and area per block. A cluster is a collection of different components in Grasshopper that supports the structure and transparency of the definition. The definition structure was developed entirely by the author, except for the parcel components of the DeCoding Spaces Toolbox.

The input parameters for the building cluster are density in numbers [density], or manually defined minimum and maximum floor height [min\_floors] [max\_floors], a seed for the height variation within the buildings [seed], the floor height [floor\_height] and the base height which defines the ground plane of the building [base\_height]. The base height for a building is needed, for example, if offices or other uses are situated on the lower floors.

**Intelligent Geometry by User Text.** To ensure real-time control on the planned building geometry, the calculated areas and heights, in every step of the planning course, the application of user text chosen. While working on a scenario, the performance indicators are shown in Grasshopper and on-screen

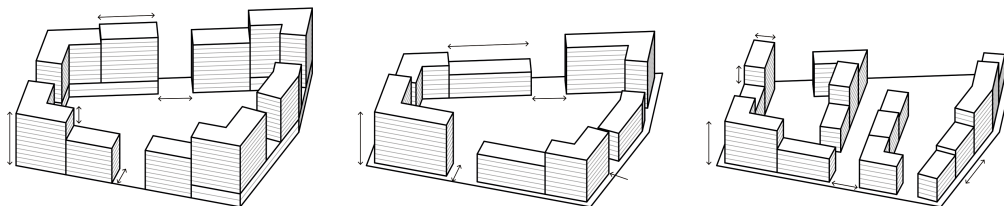
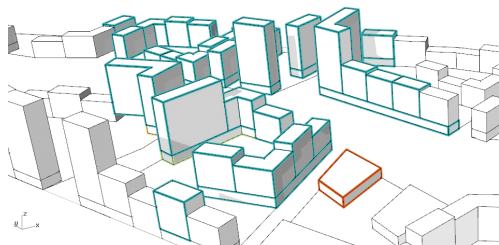


Figure 3  
Parametric input  
parameters for  
residential typology  
generation are  
illustrated

within the Rhinoceros 3D viewport. However, this information should not be lost by data exchange and therefore, is stored as attributes on the geometry itself. For this reason, user text is utilized to store keys and values on the geometry objects. This user text can be retrieved, modified, and added from a self-programmed Python toolbar in Rhinoceros 3D to extend the user experience. Interviews with experts from research and practice have shown that the use of Grasshopper and parametric design tools is considered positive, but is not yet state of the art in practice.

school: 3278 m<sup>2</sup>  
commercial: 19253 m<sup>2</sup>  
office: 69384 m<sup>2</sup>  
residential: 96026 m<sup>2</sup>  
selected GFA: 187041 m<sup>2</sup>



The Grasshopper library Human [url-8] allows displaying geometry information on the screen, whereas the generation of user text needs the Grasshopper library Elefront [url-5]. The correlating Grasshopper definition consists of a simple input formed by the building volumes, a self-made cluster component that processes the information and the preview components as visual output.

Another advantage is that developed design scenarios can be flexibly extended or changed, and the building geometry is automatically updated. For parametric models, a design freeze can help to adjust designs in response to comments or discussions manually. This fluid exchange of parametric modeling and traditional design allows the planner's intention and design intent to be optimally integrated into the workflow.

#### 4 Simulation and Analyses

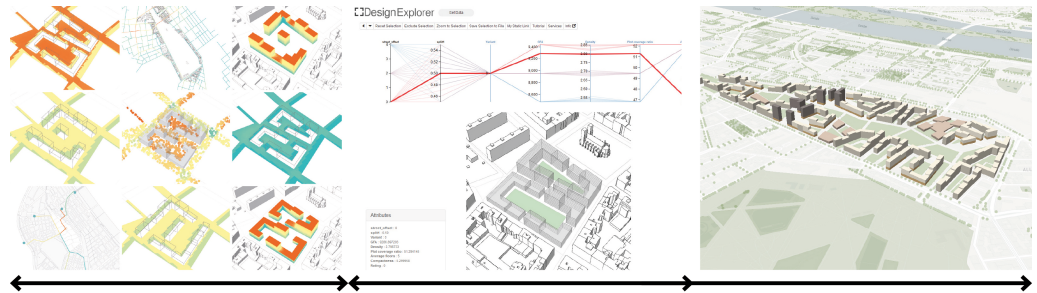
In addition to that, the real-time analyses and simulation capability of Grasshopper models allows fostering the complexity of design variants. For this reason, available simulation tools (Ladybug [url-6], Honeybee [url-6], DeCoding Spaces, Envi-Met [url-14]) were used to evaluate the designs regarding the key parameters in geometry, accessibility, visual integration, and environmental performance.

**Geometry.** To describe the urban morphology of the scenarios, the building coverage ratio (BCR), average building height (BH), and compactness (C) were used (Xu 2017).

**Accessibility.** The accessibility and walkability measures of variants are considered as essential quality aspects to develop a sustainable design and comfortable environment. Therefore, the analysis of the real walking distances to the closest public transport stops was tested using graph analysis via the DeCodingSpaces Toolbox. As a result, the use-distribution layout has undertaken some relocation of amenities to provide a good balance infrastructure across the property.

Figure 4  
On-screen  
indicators for  
design scenarios  
are displayed as live  
feedback

Figure 5  
Methodology steps  
4-6: Analyses and  
Simulation, Design  
Evaluation and  
Visualization



**Visual Integration.** The visual integration analyses are executed for the different typologies using locations in the public realm that represent a person. These studies express the perception on eye level on open space and the views from the windows. The isovist analysis component by DeCoding Spaces was used and includes various other output parameters (e.g. visible area) to explore the public realm for pedestrians. Since the boundaries of buildings are used as obstacles for the analysis, this method can also analyze a 3D isovist considering the building's volumes.

**Environmental Performance.** To evaluate the environmental performance of the typologies, the solar radiation analyses, and the outdoor comfort calculation are executed using the libraries Ladybug and Honeybee within the Rhinoceros 3D and Grasshopper workflow. Ladybug tools focus on environmental design and simulate sun and shadow studies. Honeybee allows running simulation on energy demand and microclimate. Considering these aspects by using lifetime feedback, the scenarios can be further optimized, and consequently, the quality of the design increased (Roudsari 2013). Additionally, microclimate and CFD simulations were executed in Envi-Met, whereas the simulation file was written straight from Grasshopper and evaluation results read back into the design definition.

**Solar Radiation.** First, the solar radiation studies are carried out using the plug-in Ladybug within Grasshopper that revealed the morphological differ-

ences throughout the typologies. The results of these analyses are processed graphically and as solar hours per year and  $m^2$  on the buildings envelope.

**Outdoor Comfort.** The simulation of outdoor comfort in the public realm is simulated in microclimate models, energy performance, and fluid-dynamics of winds. For the evaluation of this output data via comfort indices, an Envi-Met algorithmic app called Envi-bug was developed to rapidly calculate the distribution of local Predicted Mean Vote (PMV) using the library Ladybug (Fabbri 2017).

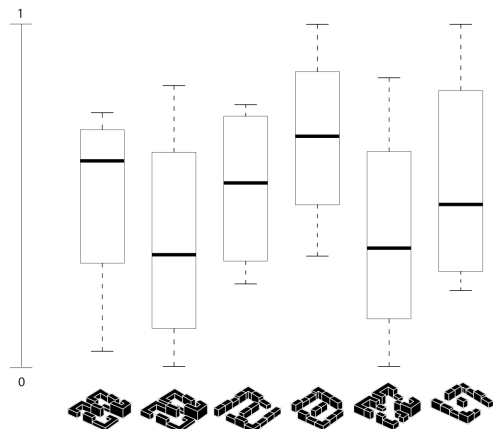
As input for the outdoor comfort calculator component by Ladybug the building geometry and weather files (epw, stat) for Vienna are needed. The epw file for any location is provided by Energyplus and can be downloaded [url-19]. The analysis can be executed for a whole year or a selected analysis period. The output of this component is the universal thermal climate index (UTCI), the condition of the person in the form of a stress level and the percentage of the time this space is considered as comfortable. The UTCI value is given in degrees and describes how the weather situation is felt by a person, including solar radiation, humidity, and wind speed.

The evaluation matrix of the scenarios as an average value of all analysis points reflects the outdoor comfort calculation. The pedestrian comfort is considered to reveal the quality of a design and therefore requires attention. The microclimate map shows the expected temperatures and the stress condition of a person. This stress condition ranges from -3 express-

ing intense cold stress to +3 substantial heat stress. The calculation was done at noon for the January 21st as coldest day and August 21st as hottest day as a representation for the entire year.

### 5 Design Evaluation

As a result, analyses result-based assessment for the design proposals facilitates to achieve a high-value urban design. The result data analysis and visualization within the environment of Grasshopper can be performed with the toolset by DeCoding Spaces. The box plot figure that illustrates the evaluation matrix for six different typologies was created using the data analysis component and represents all simulation results. The comparison of varying performance values within the parametric design surface in diagrams enables the targeted adaptation of parameters during work and avoid switching between various applications (Abdulmawla 2018).



**Design Explorer.** In addition to a numerical result evaluation and illustration, an open source online tool for exploring design spaces by Core Studio, the Design Explorer, was deployed [url-12]. The interface allows the visualization and filtering of design and group iterations that are related or scattered across the possibility of space. CSV-files (Comma Separated

Values), images, and spectacle models are generated in Grasshopper and used as input for the design space data.

### 6 Visualization

Generally, urban planners, architects, and designers are used to maps and graphical representations of their design as can be seen in the graphical representation of one shortlisted scenario. On the contrary, different stakeholders might need a diverse representation to understand and experience a design proposal. Thus, after filtering the scenarios and reducing the number of possible solutions, a suitable presentation of the results is needed. Therefore, an online platform using Mapbox [url-11] and an AR app using Vuforia [url-15] within Unity [url-16] were deployed as visualization tools.

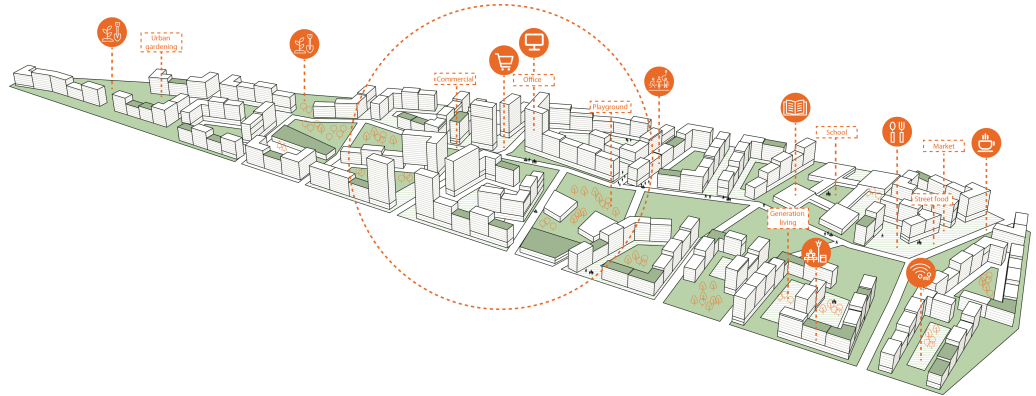
**Online Platform.** To provide online access to the proposed geometry is recognized as an easy way to share information with clients, stakeholders, and citizens. The interface and navigation of online maps are well known by most of the people and can help as a negotiation base. For this reason, a location data platform called Mapbox was used to create mobile and web applications. Mapbox provides building blocks where locations and features can be added in a developer-friendly interface. Further, this open source tool allows the visualization of properties in 2D and 3D volumes to facilitate an understanding of sizeable geographic data. For the master plan project, a Mapbox based website was developed that allows switching the preview of three shortlisted scenarios in context.

**Augmented Reality App.** The suggested framework uses the Vuforia engine, an AR platform, allows to develop apps and supports phones, tablets, and digital eyewear across Android, iOS, and UWP. Vuforia engine used within the game engine Unity offers the creation of AR experiences of different scenarios and supports the user to understand the design in a better way.

First, the geometry is exported from Rhinoceros 3D as a 3ds file as meshes and second, an image that

Figure 6  
Box plot  
representation of  
simulation results in  
normalized scale for  
different typologies

Figure 7  
Graphical  
illustration of the  
Master Plan in  
Vienna



serves as a target image for the app and gets tracked by the camera. Next, the position of the geometry in spatial relation to the image target is set in the game engine Unity and the app compiled as an Android app. Finally, the app can be executed, and the design scenarios experienced by overlaying the geometry as 3D volume on top of the target image.

Figure 8  
User experience via  
AR app of the  
developed Master  
Plan in Vienna  
Photograph ©  
Art-Media [url-22]



## RESULTS & DISCUSSION

In conclusion of the presented framework, it can be said that the use of digital tools and methods can increase the planning efficiency and variety. Likewise, the influence of the designer is particularly needed in the phase of concept development and design development. Therefore, understanding the cultural and historical aspects of the site in combination with the analysis results is necessary to obtain an excellent de-

sign concept.

As can be seen, the work with the parametric plug-in Grasshopper offers numerous advantages in the generation of various design case studies. The flexible way of working and the handling of large amounts of data are only two of them. Importing data from different systems and switching between various applications and formats is a challenging task that requires further investigation and improvement. To summarize, this suggested workflow reveals a high potential with the implementation of digital tools. Another advantage of this step by step process is the possible computer-human interaction that allows accessing this framework at any step.

## FUTURE RESEARCH

Ultimately, the established parametric methodology includes currently available digital tools, plug-ins, and data sources, but is planned to be enhanced by the integration of machine learning and optimization processes as a next level. Furthermore, cultural aspects can be considered through the involvement of citizens. Participation platforms, tools, or applications can be developed and incorporated into this process to address and screen citizens' needs.

It can be concluded that the application of digital tools within the urban planning process is state of the art, in business and research. Towards an effi-

cient workflow in the future, open source tools will be considered as a driving force to support the research. The collaboration between different institutions and the share of knowledge is critical to strive for better solutions.

Finally, due to a large number of different analysis and simulation tools available with strongly fluctuating performance, benchmarking with a focus on application and result quality is essential. Therefore, the development of a strategy for interdisciplinary data exchange is considered as an enrichment to this methodology. The importance of seamless information flow is seen as an essential part to achieve, for instance, the data exchange workflow with regard to Building Information Modeling (BIM). This has already been successfully established and should also be employed to the field of urban design standards.

## ACKNOWLEDGMENT

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