Visibility Analysis for 3D Urban Environments

Research development and practical application

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Abstract. *This paper presents a visibility analysis tool for 3D urban environments and its possible applications for urban design practice. Literature exists for performing visibility analysis using various methods and techniques, however, tools that result from such research are generally not suitable for use by designers in practice. Our visibility analysis tool resides in Grasshopper, Rhino. It uses a ray casting method to analyze the visibility of façade surfaces from a given vantage point, and of a given urban setting, in particular, buildings and roads. The latter analysis provides information on the best visible buildings/ building facades from segments of roads. We established a collaboration with a practicing architect to work on a design competition together, using this tool. The paper elaborates on the visibility analysis methods, presents the tool in detail, discusses the results of our joint work on the competition, and briefly reflects on the evaluation of the use of the tool by design practitioners.*
Keywords. *Visibility analysis; pedestrian design; urban space quality; design practice.*

INTRODUCTION

This paper presents a visibility analysis tool for 3D urban environments and its possible application for design practice. Visual perception of space is one of the factors that defines spatial experience and cognition of architectural/urban space. Analyzing the impact of design decisions on perception of space may help to significantly improve the quality of urban developments (Bittermann et al., 2008).

Many design and architectural researchers investigated the relation between urban space morphology and its experiential qualities as perceived by users. Among them are Appleyard et al. (1964), Lynch (1960), Benedikt (1979), and Thiel (1961). Kevin Lynch stipulated on the importance of view analysis and

methods of analysis using terms such as "visual absorption", "visual corridor" or "visual intrusion" (Lynch, 1976). A view analysis example is an 'isovist' analysis which measures a volume of space that is visible from a single point in space. The term was introduced by Tandy in 1967 (Tandy, 1967). This research gave raise to the development of a multitude of methods for quantitative analysis of space perception. Benedikt was the first who introduced a set of analytic measurements of isovist properties (Benedikt, 1979). In the field of landscape architecture and planning there is a similar concept called "viewshed" (Turner et al., 2001), which analyzes the visibility of an environmental element from a fixed vantage point.

Quantitative methods for visibility analysis can be roughly divided into the following categories: a) scientific landscape evaluation (LE) provides methods for 'quantitative description of natural landscape visual quality or impact prediction' (these approaches do not consider human perception); b) methods such as 'isovist' concentrate on the visibility of an environmental element from a fixed vantage point and neglect the landscape resources (He et al., 2005).

The most common examples of utilizing visibility analysis methods and tools in the field of urban design are analysis of visibility from important (strategic) points (e.g., large transportation hubs, major public spaces, etc.) to dominants (e.g. tall buildings, monuments, etc.), which can help to improve navigation of pedestrians in the city. Another case is the preservation and/or strategic use of views to natural landscape elements such as a river or park. This is especially relevant to high-density urban areas that are still undergoing an extensive development process, such as Moscow, Hong Kong or Singapore. Uncontrolled development in such big cities leads to fragmentation or complete blockage of views to valuable landscape resources, which are more desirable for people than man-made structures (He et al. 2005). This results in a drop of real estate values and deterioration of city fabric. In this context, He et al. (2005) presents an approach to visual analysis of high density urban environments, which quantitatively integrates human visual perception (analysis from a fixed vantage point) with the visible landscape resources (LE), using GIS as database and technical platform. This approach can help architects to take more informed decisions at an early design stage regarding the preservation of valuable landscape resources and view corridors. Another example is the work described in Fisher-Gewirtzman et al. (2005), which compares various coastal urban morphologies with the variation of density levels and their influence on the visibility of the water front. The assumption is that the morphological results can be used as criteria for future urban planning.

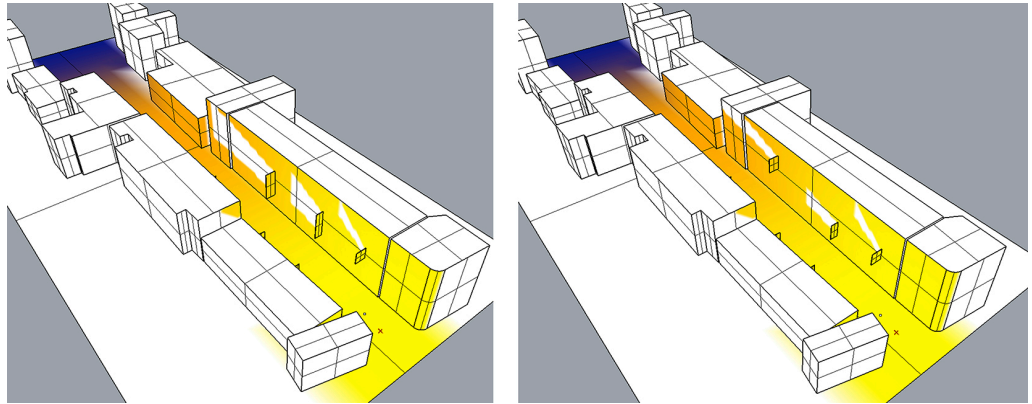Do and Gross (1997) present a set of tools for spatial analysis among which are tools for visibility analysis performed using different computational implementations. The research underlines that different computational methods tackle different aspects of spatial analysis and provoke different ways of thinking about a problem. Therefore, a computational tool can become a flexible element that supports creative thinking during design process.

Turner et al. (2001) uses visibility graph method, first introduced in De Floriani et al. (1994), for spatial analysis of architectural space. This research investigates how visual characteristics of a location are related and how this can have a potential social interpretation. The graph representation that is used incorporates isovists to derive a visibility graph of mutually visible spots in a given spatial layout (Turner, 2001). This leads to the definition of some measures that describe both local and global spatial properties that may relate to the perception of the built environment.

The literature discussed above presents research for performing visibility analysis using various methods and techniques. An issue that arises concerning the tools that result from such research is that the tools are not suitable for use by designers in practice. Most designers do not have knowledge and skills of programming, or using specialized software. This has several reasons, e.g., time pressure in a design project. Designers also don't tend to use specialized analysis software during the early design phase, because these are difficult to use, and the model usually needs to be exported and imported back and forth between the analysis and modeling software. Performing analysis on the model in the familiar modeling environment would increase the usability of these tools. Furthermore, developing the tools with their use by designers in mind would increase their usability. Our research development aims to introduce visibility analysis tools in the urban design practice.

The most recent visibility analysis methods that designers and architects use today rely heavily on computing power. Some of the well-known analysis software such as, Ecotect, Space Syntax and ArcGIS offer methods for visibility analysis. However, these

offer very limited methods for visibility analysis of building facades, or as we call it in this paper, analysis of 3D urban environments. In addition to that, all this software are standalone applications that do not support 3D modeling. Every new design version must be imported and analyzed in a modeling software. This approach does not support dynamic manipulation of the design model and slows down the design process. We developed a tool for visibility analysis in Grasshopper, parametric plug-in for the Rhinoceros modeling platform. Rhino is widely used among architects and designers today. Our tool can be used to analyze models directly in Rhino, and dynamic changes can be made and revised models analyzed by the tool in real time. Our tool uses a ray casting method to analyze the visibility of façade surfaces.

Our tool combines two possibilities, referring to the two quantitative methods for visibility analysis described earlier in this section: a) analysis of visibility from a given vantage point and; b) visibility analysis of a given urban setting (in particular, buildings and roads). The latter analysis provides information on the best visible buildings/building facades and segments of roads that 'see' most of the buildings.

The view pollution analysis became a first case study for the tool (Koltsova et al., 2012). An example that we analyzed is one of the pedestrian streets in the historic center of Moscow, Russia (Figure 1). Bill-

boards and other large signs create a view pollution of building façades on this street. The definition of view pollution may be interpreted differently in different contexts. For instance, billboards and signs characterize Times Square in New York, as these form the identity of place in this context. However, on this pedestrian street in Moscow, uncontrolled placement of advertisement billboards results in a complete blocking of 18th century historic heritage buildings. Furthermore, the scene created by the signs do not contribute positively to the identity of the place, on the contrary, it diminishes the overall quality of public space.

In our current work we aim to investigate potential uses of our tool for design practice. Therefore, we established a collaboration with a practicing architect to work on a design competition together, using the 3D urban settings visibility analysis tool.

This paper elaborates on the visibility analysis methods, presents the tool in detail, and discusses the results of our joint work on the competition. We end the paper with a brief evaluation on the use of the tool by design practitioners, and directions for future work.

THE VISIBILITY ANALYSIS TOOL
This section elaborates on the functionality of the visibility analysis tool and its development process. We used Grasshopper, the parametric environment

for Rhinoceros, as the development platform. In Grasshopper it is possible to write your own code in C# .NET or VB .NET and create a custom tool (or component) that performs the specific function. Such custom components require potential users (architects and urban designers) only to know what to feed in as an input (curve, points, geometry, etc.) and what the output would be. We developed two custom tools that perform the following functions: visibility analysis of building geometry, and visibility analysis of the road network (Figure 2). Visibility analysis uses a ray casting method. The algorithm requires the following inputs:

- building geometry as Breps
- terrain as a mesh surface
- road network as curves or polylines

The algorithm converts the building geometry (Breps) into a mesh. The possibility to define mesh tessellation for building and terrain surface geometry individually is embedded in the tool. This is done due to the difference in scales and analysis precisions for the two geometry types.

The road curves are selected automatically by a "Pipeline" component (Figure 2). This is the in-built Grasshopper component that allows for automatic selection of a specified type of geometry by object layer. The road network is split into segments and at intersection points. The length of every segment can be defined according to the design scale. The smaller the segment the more precise the analysis is. The mid points of segments become visibility nodes. The algorithm generates rays between mid points of the curves and mid points of mesh faces of building/terrain geometry. Then, the algorithm returns intersection points between vectors and each face's mid points and checks if there is any obstruction between the viewing point and façade surface. Depending on the result it assigns each face a color: gradient between yellow (best visible and blue – worst visible; white – non-visible) (Figure 3).

In order to save calculation time we use bounding box of building meshes at first iteration step to check for possible intersections. If generated ray intersects a bounding box then the algorithm pro-
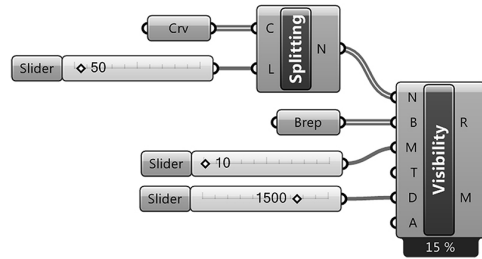
ceeds to the analysis of the whole mesh. Intersection calculation of the ray and bounding box takes less time then ray-mesh intersection, which helps to considerably reduce calculation time.

The main parameters that the tool uses are:
- the view distance from a view point to a façade surface,
- maximum visual angle (vertical and horizontal), and,
- angle from the view point to a façade surface.

For different design tasks specific parameters are retrieved by the tool. For example, for the analysis of city dominants (tall buildings or city monuments), the tool solely checks if the object is visible or not from a certain point or path (Figure 4a). Considering factors such as the visibility of city dominants during the design of new public spaces can improve navigation within a city. For pedestrians it is easier to choose the direction of movement if they see a dominant and know the location of it. Visual connections in the city also help to create better
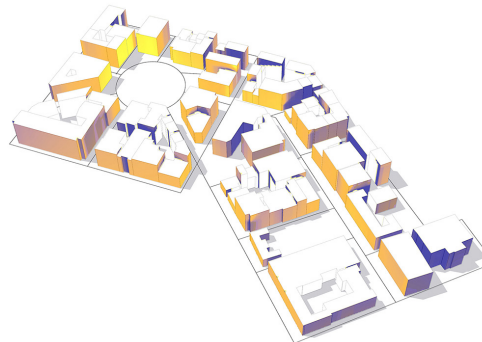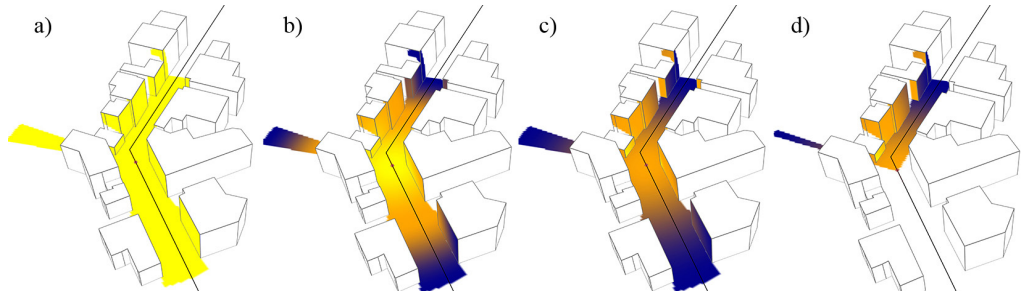

Figure 3
Analysis results (best visible – yellow; non-visible – white), viewing points are distributed along the pedestrian walks with a span of 20 meters.

connected public spaces (network instead of isolated spots).

For the analysis of how detailed pedestrians can see the facades and which are the most exposed surfaces, the maximum distance and angle from a view point to façade mesh faces is added. An angle closer to 90 degrees and less distance to façade means better visibility. Gradient illustrates the best/average/worst visible façade surfaces (Figure 4b, c). For the moment the influence of distance and angle on the analysis result is 50/50. Naturally, the importance of each of the parameters can vary depending on the design task. Therefore, we plan to further evaluate the tool with architects and revise it based on their feedback. We have already added additional constraints such as the horizontal and vertical view angles to be able to analyze what a person can see while walking in a specific direction (Figure 4d). It is possible to activate or deactivate the functions described above by right-clicking the title of the component and checking/unchecking them (angle to surface, distance to surface, one direction). This is a feature that can be programmed by a tool developer in Grasshopper.

In our work we combined two types of urban analysis: visibility and accessibility. With the accessi-

bility tool it is possible to set a starting point and analyze how far one can get by walk/car or bus within a certain time period. In this case destination points are the mid point of previously generated segments of the road network (refer to the visibility tool description before). The input parameters for this component are:

- max walking distance, or;
- time and speed by car/walk/public transport (in which case max walking distance is calculated based on these two parameters).
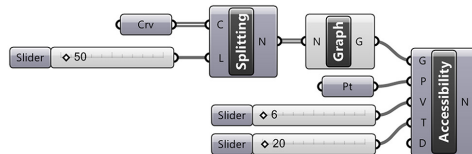
We use the graph component to analyze structure and create topology of the road network (Figure 5). This information in turn is used by the Dijkstra's algorithm to calculate the shortest path between starting and destination points.

Combining the two types of analysis methods provides the possibility to analyze how far one can go within a certain time span and what one can see while walking this route (Figure 6). Figure 7(a) shows the accessibility analysis results and (b) what one can see while walking this path. The resulting path is used for the visibility analysis of best visible façade surfaces from the path. Rays are created between the road segment and building mesh faces. If a mesh face is visible from the road segment then the algorithm assigns a segment ID to the mid point of the mesh face. The more segments "see" a certain mesh face the higher the mesh face's visibility value becomes (in terms of color: yellow – best visible, blue – worst visible, white – non-visible).

Using our tool it is also possible to analyze best visible buildings. In this case the algorithm stores

building IDs instead of individual mesh faces and analyzes what are the buildings that most of the road segments can "see". The same logic applies to road segments. The more buildings/mesh faces a road segment can "see" the higher visibility value (closer to yellow color) is assigned to it (Figure 7b, c).

Using the tool it is possible to analyze the visibility of a single building and the road segments that can "see it" (Figure 7d). The algorithm principle is the same, with the exception that the information of the road segment is stored as a boolean (True/False).

PRACTICAL APPLICATION OF THE TOOL

We worked with a practicing architect and applied our tools for a design competition. The brief was to develop a design proposal for the transformation of a former industrial area into a techno park. This new development is supposed to become a new local economic center and attraction point. Therefore, its visual perception from the main access points, such as bus stops, train station and highway, is an important aspect for analysis as it directly influences the accessibility and integration of the new development within the local context.

Figure 8 presents the design proposal. According to the task set by the architect the tool checked for visibility from important points around the project site (points in orange), such as bus stop, city public space and tram stop, to objects on the project site (i.e. design dominants such as conference center, old factory chimney etc.). The analysis process is shown in Figure 8, right side. The idea of the architect was to have a so called "target" matrix where he documents which elements should be seen from important view points according to his design concept (Table 1). The tool analyzes each new design scenario and creates a new matrix (Table 2). This matrix is compared to the target matrix and if there are discrepancies, building shapes are adjusted to provide better visibility. For the moment this process of changing the design based on the target matrix is manual. We are convinced this method is more intuitive for an architect and provides more control on the design process.
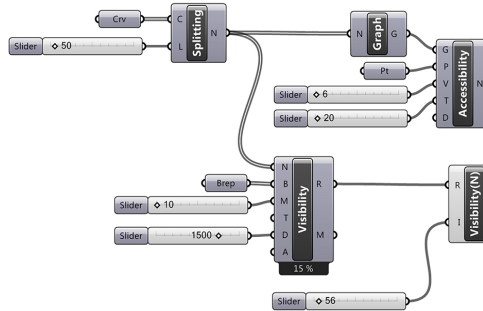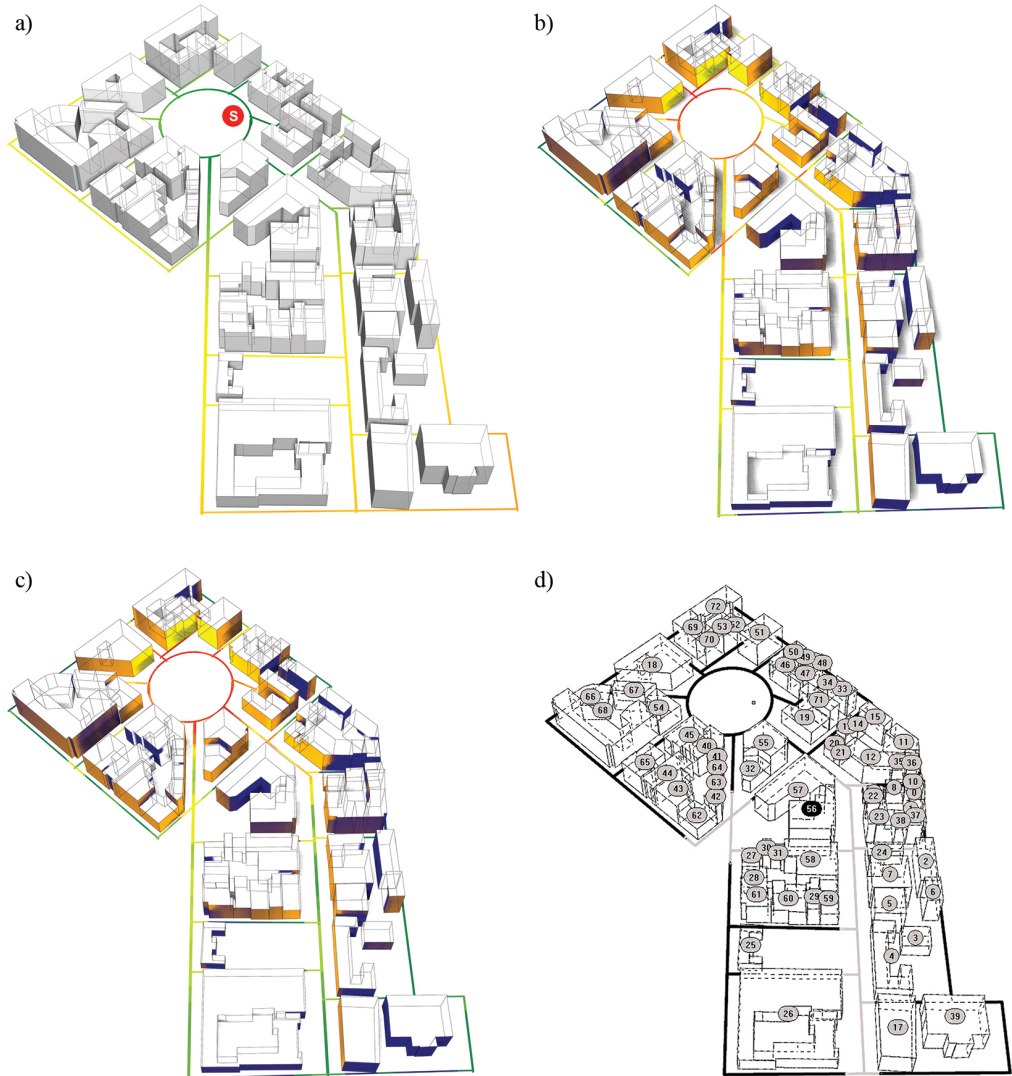
EVALUATION

During this collaborative work it was important for us to understand what the challenges are that prevent architects from using parametric tools and what should be changed (in the design process/tool functionality) to integrate these better into the design practice. We have conducted an interview with our partner where we obtained his opinion about the general situation and about using our tool in particular. In general, the use of tools depends on the size of the office and the scale of the projects in this office. In Switzerland, rapid urban expansion was not such a dominant issue until recently. People do not yet feel the influence of it on their lives, therefore, there are not that many design offices that deal with such challenges, and consequently, have a need to upgrade their processes or tools. Another, quite a straightforward reason, is that people are used to certain software and associated processes that they establish in their offices and as there is no immediate need, they don't want to change anything (or have time to change the routine). "As long as it works, its fine".

The architect that we have been working with is one of the few whose office deals mostly with urban design projects. He works mainly using traditional approaches when designing, which are usually sufficient. However, he remarks that the parametric approach is sophisticated, because it helps to resolve many different challenges by allowing the architect to systematically explore on a few issues at a time. His feedback on our tool was that this tool becomes

really useful as soon as the 3rd dimension comes into play. Architects are trained and can estimate what a person can see on the plan. However, when elements of context such as a complicated terrain with high-density developments are a part of design project, then it becomes quite hard to estimate the visual impact of the new design and its perception from different city locations. In his opinion, our tool can be used for the projects with, as he called it, "multiple levels and dimensions". Based on the feed-
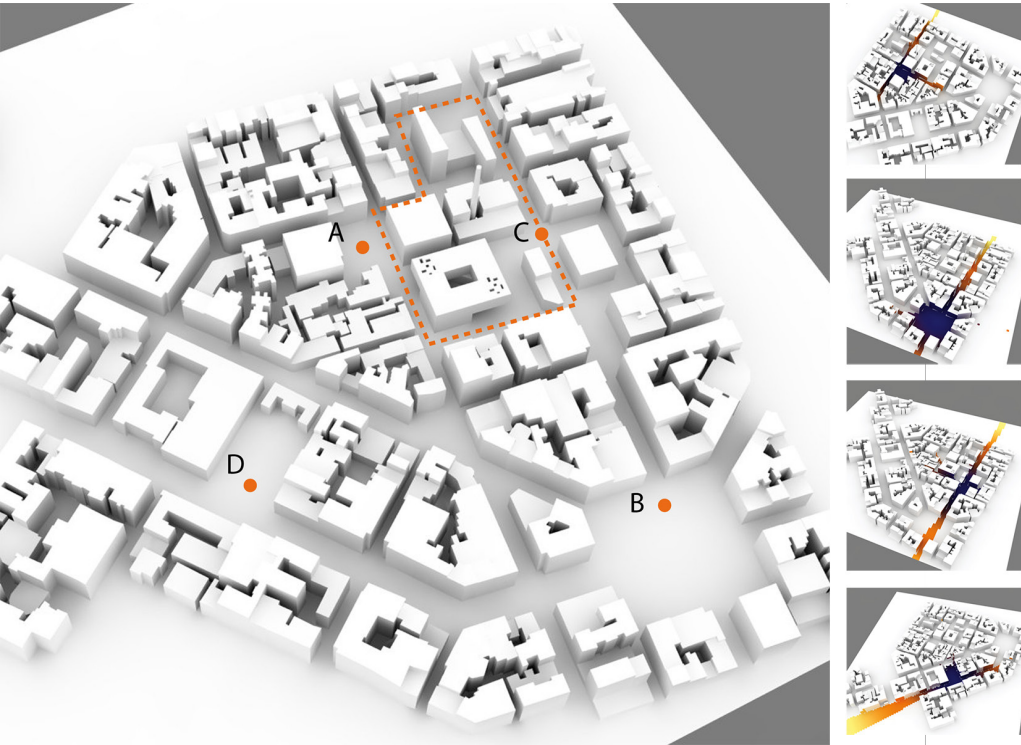
Figure 8
Top: project site and design
proposal; right: visibility
analysis from strategic points
(street view, tram stop, bus
stop, point in the city)

back we introduced additional function that allows for terrain surface visibility analysis. The meshing of the terrain surface can be controlled individually due to the scale difference and analysis precision of the two geometry types (Breps – buildings, and surface - terrain). The parametric nature of the model allows for an interactive change of the design form in order to improve the visibility.

	1 chimney	2 research lab	3 conference c.	4 admin offices	5 entrance N
A street view				▓	
B tram stop	▓		▓		▓
C bus stop					
D point in city		▓			

Table 1
Reference matrix.

	1 chimney	2 research lab	3 conference c.	4 admin offices	5 entrance N
A street view				▓	
B tram stop	▓	▓			▓
C bus stop	▓		▓		
D point in city		▓		▓	

Table 2
Matrix for one design scenario.

CONCLUSIONS

This paper demonstrates the working process between a research group and a design practitioner. The application of parametric tools for design practice has the potential to establish a better communication between design theory and practice, and improve the quality of future urban spaces through better informed design processes. We will proceed with collaborative work with architects in order to enhance our methods and adapt them to the needs of the design practice.

In our future work we also plan to enhance the functionality of the presented tool by introducing additional inputs based on architects' feedback. For example, it is important to consider in the analysis the type of urban space and the type of movement it implies. In more specific terms, square/piazza or a shopping street implies lingering. The road between the transportation hub and business district would most probably have linear/directional type of movement. The perception of space by pedestrians largely depends on these factors and we will work on the ways to introduce this information into our parametric tools which would result in more accurate results.

ACKNOWLEDGEMENTS

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