

Tangible Grasshopper

A method to combine physical models with generative, parametric tools

Boris Plotnikov¹, Gerhard Schubert², Frank Petzold³

^{1,2,3}Technische Universität München / Chair for Architectural Informatics

¹pborisp@gmail.com ^{2,3}{schubert|petzold}@tum.de

The use of digital tools in the early, creative design process is the focus of an interdisciplinary teaching and research project. Starting from the question of how a seamless connection between physical and digital tools could be made possible, the proposed method tries to bridge the gap between both methodologies and provide intuitive, visual and collaborative design coupled with advanced, real time computer simulations. A design platform has been developed which supports a seamless connection between freely shaped physical models, GIS data and Grasshopper3D. The environment combines the reconstructed physical models with the digital one (surrounding buildings) and passes the information to a custom Grasshopper3D plug-in which serves as a link to existing and custom developed simulative tools. All simulations are performed and visualized in real time to support the intuitive and iterative design process.

Keywords: urban design, tangible interface, grasshopper, sustainable design, design decision support

INTRODUCTION

Physical models have always played a central role throughout the design process for architects and urban planners. Such models help in analyzing and understanding the context, intuitively convey design ideas and work collaboratively. In the last few decades and with the popularization and enhancements in the field of computation, computer tools became prominent in the field of architecture, first mainly as tools to enhance efficiency and produce technical drawings, but in recent years also as decision support tools in a variety of fields such as climate, construction and mobility. As these tools grew to be more advanced they usually also grew in complexity, often resulting in a less intuitive process and

requiring a long time to master. Such advantages and limitations have been discussed in previous studies (Weytjens et al. 2012).

The proposed method tries to bridge the gap between the physical and digital design methodologies and provide intuitive, visual and collaborative design coupled with advanced, real time computer simulations. A physical design platform has been developed which supports a seamless connection between freely shaped physical models, GIS data and Grasshopper3D. The environment combines the reconstructed physical models with the digital one and passes the information to a custom Grasshopper3D plug-in which serves as a link to existing and custom developed simulative tools. All simulations are per-

formed and visualized in real time to support the intuitive and iterative design process.

BACKGROUND

As CAAD tools grew in popularity, their influence and reach expanded to a wide array of spheres including but not limited to structural, climate, energy use, acoustics and mobility analysis. The use of these tools, which were hard to master and very specific was usually limited only to specialists, resulting in a linear process where many evaluations were conducted only after the design process for validation purposes and not assisting in informing the design. In recent years there have been multiple attempts to bridge the gap between architects and other professions involved in the building industry by grouping and incorporating evaluation and simulation tools in existing CAD and BIM tools, notably on top of Rhinoceros and Grasshopper3D. Some of these tools are Diva [1], a daylighting and energy modeling plug-in and Ladybug and Honeybee (Sadeghipour-Roudsari and Pak 2013), two open source environmental plug-ins meant to help designers create an environmentally-conscious architectural design. Recently a plug-in called UMI (Reinhart et al. 2013) used to evaluate the environmental performance of neighborhoods and cities was also released. In contrast to Diva, Ladybug and Honeybee, UMI focuses on the urban context, providing less detailed, larger scale results.

These and other tools simplify the evaluation of designs by allowing the user to model and run simulations in a single program, eliminating the need to master a variety of tools and minimizing the risk of incompatibilities due to manually converted geometry. While running some of the simulations inside the plug-ins, more advanced simulations are being run by verified tools in the background such as Radiance (Ward and Shakespeare 2004) and Daysim (Reinhart and Walkenhorst 2001) for daylight simulations and Energyplus (Crawley et al. 2000) and OpenStudio (Guglielmetti et al. 2011) for energy and thermal simulations. Although these tools help to inform the

design from rather early stages, the process of setting up the models and running the simulations is still time consuming and the interaction with the model is limited and requires technical expertise.

APPROACH

Typical design workflow is becoming increasingly interlinked with digital tools, especially when addressing the neighborhood and the urban scale. As a direct result, professionals involved in urban design and planning require longer technical training, not necessarily for their main expertise but in order to keep up to date with current digital tools. The nature of working in front of a screen does not promote collaboration, especially in the design realm, and people from different fields without knowledge in the used software are excluded from the process altogether. As collaboration is at least at times mandatory, both for approval of projects and for discussions between designers, consultants and decision makers, the design process is often paused and much work is spent preparing a simplified and accessible representation of the progress. At times such representations are meaningful and concise, but more often they are simplified and partial and potentially not representative of the bigger whole. Often the design is paused and static representations such as images and schemes are produced. A task which is time consuming but more importantly disconnected from the actual design. One of the unfortunate byproducts is that these collaborations are occurring seldom and at later stages of the design, by which point fewer changes are likely to occur.

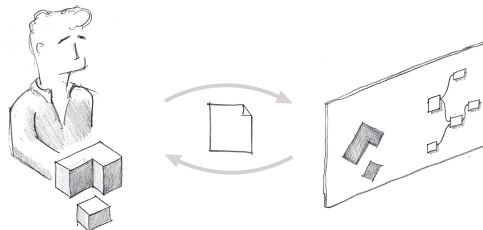


Figure 1
Seamless
connection
between tangible
objects and
Grasshopper 3D.

The method proposed addresses these limitations and suggests both a conceptual shift in common design practices and a practical solution which facilitates such a shift. By first minimizing configuration and setup time by seamless GIS integration, a physical design platform and a set of predefined digital simulations the process can start much faster and allows the participants to focus on design rather than on technical aspects. Once started, the process no longer needs to be fragmented and disconnected. The designer can work in an intuitive physical 3D environment by manipulating physical masses on top of the digital data or in a digital environment taking advantage of commonly used and validated tools and simulations, Rhinoceros3D and Grasshopper3D serving as the digital environment as well as the bridge for other software. Both processes complement each other as they are different ways of working with the same model, meaning no conversion or synchronization is required. Such a setup is also more convenient for showcasing and discussing designs in larger and sometimes cross disciplinary groups. The process does not need to be paused, represented in another way for a different audience and then converted back, rather one continuous iterative process with an efficient feedback loop exists, harnessing both advanced digital tools and physical intuitive design strategies.

By linking between digital tools with physical models which require no configuration or program specific knowledge, the proposed method addresses the early stages of design, when very little apart from the context is already known. As such the urban and neighborhood scales are targeted and the method provides quick and meaningful simulations which evaluate design decisions such as massing possibilities and their effects on surrounding buildings and the public realm. By linking this tool with existing design tools such as physical models, it is possible to control and monitor simulations through already established mechanisms. For example, changes made to the physical model will have an immediate and direct effect on the results of digital simulations and

analysis. This allows for a quick assessment and comparison of the potentials and issues of design variants, directed and determined by developments made in physical models. It is also important to note that more detailed and accurate simulations are to be performed at the building scale at a later stage when more about the design is known. Thus the proposed method provides a complimentary and an intuitive toolset for early design stages, supporting the designer by providing real-time analyses and a qualitative comparison between alternatives.

Scenario

To illustrate the benefit of the proposed methodology, a scenario describing the development process of a new housing neighborhood was chosen. An architectural firm has won a public competition organized by the city to design the master plan for the site. There were already several preliminary meetings in which the city officials expressed their main goals and requirements and now the architects initiated a meeting with the city officials and consultants in the fields of transportation, mobility, climate, energy use and acoustics in order to discuss several massing alternatives and receive feedback. The participants are gathered around a large multi-touch table and a big screen, showing a plan view and a perspective of the site respectively. Both surfaces show the latest digital model showing a massing proposal for the site. As the architects describe the concepts they zoom in and out using gestures on the surface of the table. Other participants also engage and in addition to walking around the digital model scale it to focus on and discuss specific areas in the site in greater detail.

The architects switch between several saved variations to discuss design alternatives. At this point, the climate consultants load a real time radiation simulation to examine the amount of solar radiation on the facades of the buildings to optimize orientation, building heights and density. They identify an area which seems to be problematic and immediately remove several buildings and as they have a differ-

ent idea regarding the placement of the massing in that particular location, they take several Styrofoam blocks available, trim them to fit the shapes they envision and place them on the table. The digital model and the simulation results are updated in real time to reflect the changes. At this point the transportation expert wishes to examine the distances to the location of the planned school from all of the housing blocks. She switches to that simulation and as she is not satisfied with the results examines the effects of moving the school to another location, reordering some of the buildings and roads in the process. Now the climate engineers run an outdoor comfort simulation to examine the conditions in the park next to the newly placed school.

That iterative process continues until the experts, city officials and architects are pleased with the results. All of the participants were exposed to the process and were able to contribute. In addition the experts in different fields were able to gather together and work collectively to produce a synergistic design which is optimized not just in relation to their area of expertise but as a complex system maintaining a balance between many, sometimes opposing, requirements. Perhaps several alternatives were saved during the process for future reference and as catalysts for further development. At this point the architects are able to proceed with the design, knowing that it fulfills the requirements from all of the groups involved. There is no need for extra work to integrate the conclusions from the meeting into the design as all of the work has been done on the actual model and the design process can continue without interruptions, misinterpretations or time loss.

Related Work

As buildings grow in complexity and include an expanding number of building related professions, so does the need for better tools to improve communication and collaboration between those teams (Kalay et al. 1998). While much of the research focused on attempts to facilitate purely digital collaboration by developing custom Information communication

technology and software as described in the literary study conducted by Rahmawati et al. (2013), a second, more physical approach advocating for end users collaborating around a table has also been explored. URP (Underkoffler and Ishii 1999) is a system for urban planning which runs simulations on physical architectural models placed on a table surface, including visualizing shade for any time of day, throwing reflections off glass facade surfaces and visualizing 2D windflow. BUILD-IT (Fjeld et al. 2002) an augmented reality (AR) system, loads digital 3D models and allows users to select and manipulate them by moving physical specialized bricks which are used as interaction handlers. Offering users two views of the model, the top view is projected on the table and a side view is projected on a screen nearby. Arthur (Penn et al. 2004) is an augmented reality system which includes a head mounted display and stereo cameras facilitating the 3D view of digital models. Placeholder objects and pointing devices are used to interact with the virtual media in addition to finger tracking and gesture recognition. More recently and with the popularization of tangible user interface object markers, programming languages such as processing and parametric design environments such as Rhinoceros 3D and Grasshopper3D, more direct and intuitive workflows became possible. (Salim et al. 2010) describe the design and development of two such prototypes over a period of four days. Tangible markers representing buildings are placed on a special table, tracked and update a virtual model. Participants manipulate the markers which triggers a real time update of the virtual model. Viola and Roudsari (2013) propose a workflow consisting of an "observer" which tracks markers, an "interpreter" which analyses and assesses the observed model and a "visualizer" which displays the results onto a design space. Markers represent predefined buildings and can be freely manipulated on the design space. An incoming stream within Grasshopper3D interprets the data from the markers, reconstructs a 3D digital model, performs environmental analysis in near to real time and visualizes the results.

The proposed method shares many similarities with some of the described tools but breaks free from the digital-physical constraints, allowing for free form physical modeling which requires no pre-configuration, does not limit the user regarding materials used in building the model, and provides advanced computer simulations.

SYSTEM SETUP

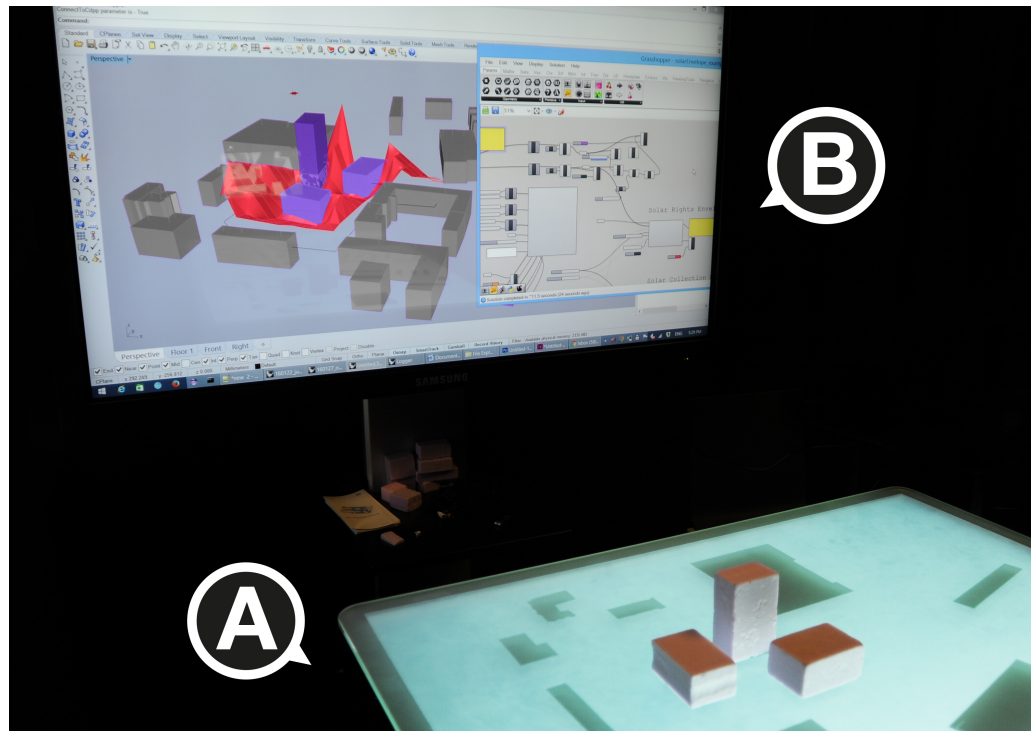
To implement the mentioned approach the system setup includes two main parts (Figure 2):

- A Design environment (Figure 2 - A) called Collaborative Design Platform (CDP) (server application) for urban planning based on a multi touch table with additional 3D-Object reconstruction

struction to digitalize physical working models placed on the table in real-time (Schubert et al. 2011) (Schubert et al. 2011) (Schubert 2014). The platform is designed to suite the needs of an urban planning in scale 1:500.

- Custom Grasshopper3D component (client application)(Figure 2 - B) , receiving 3D information and user interactions from the design platform. This component allows using the reconstructed data (geometry) from the working models seamlessly in Grasshopper3D. This connection works in real time and updates automatically.

Figure 2
System setup: (A) Design Platform: physical models placed on the Design Platform table (Styrofoam blocks) with integrated 3D object reconstruction, (B) Custom Grasshopper3D component running and visualizing simulations.



CDP - Collaborative Design Platform

The technological basis for the designed development platform is a large-format multi-touch table (Figure 3 - A) with an integrated digital 3D object reconstruction fun realtime realized with the help of a 3D depth camera on top (Figure 3 - B).

Using semantic GIS data as its basis, a digital plan is displayed on the surface of the table at a scale of 1:500. Physical objects forming design variants can be placed on the multi-touch table and a digital counterpart of them will be created automatically in real-time - without the use of markers or any other similar predefined methods. Both the digital plan of the surroundings, as well as the reconstructed shapes of the physical 3D objects can be seen in a perspective view on another, vertical mounted touchscreen

(Figure 3 - C). This means that any physical objects and their geometry will always have a digital equivalent. These counterparts are created through a coupled system. The footprint of the building is tracked by the surface of the table and an additional on-top mounted 3D depth camera scans the three dimensional shape of the object as a point cloud. Two construction algorithms were conceived to assist the process and reconstruct the point cloud. One captures the footprint of the building and extrudes it. The other records the free-form as a triangulated mesh and connects it to the footprint. A more detailed examination of this process can be found in the paper (Schubert et al. 2013).

To support the creative design process, different design approaches and the resulting use of differ-

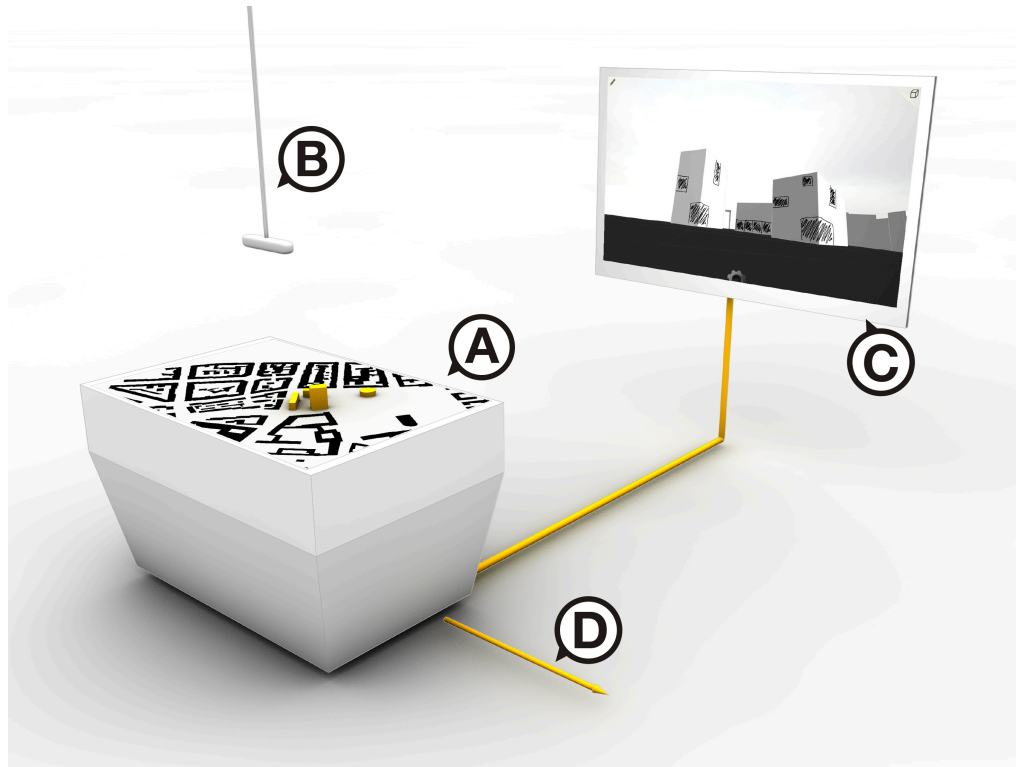


Figure 3
System setup of the
CDP. A: Multitouch
table B: On-top
mounted 3D depth
camera C:
Perspective view of
the design scene D:
Flexible extension
via a network
protocol.

ent tools, the hardware and the software of the table were designed to be both flexible and extendable. In terms of linking hardware, this is achieved using a custom developed network protocol (Goldschwendt et al. 2014) (Figure 3 - D). The CDP serves as a server-based application and provides a client with all relevant design information. This includes geometric data from digital site models, physical working models and digitalised sketches. As a result external applications, such as Grasshopper, can access and use the design information in real-time.

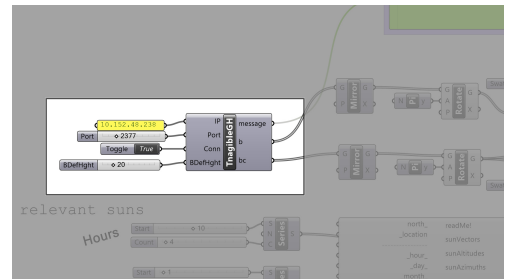
Grasshopper component

A custom component which facilitates the communication between the CDP platform and Rhinoceros3D, including Grasshopper3D and all the other stimulative tools previously mentioned has been conceptualized and developed with several key points in mind:

1. Allow for a stable and persistent connection between the CDP platform and Grasshopper. This connection first establishes a link to the physical model and reconstructs it in Grasshopper and then ensures that any updates to the physical model translate in real time to Grasshopper and in turn to any further logic which is defined. On top of creating a physical input stream, the component extends upon the usual functionality of Grasshopper by allowing for dynamically defined input geometry which frees the user from configuring input parameters and allows them to focus on designing while providing constant input from any running simulations, maintaining a feedback loop which informs the design.
2. Accurately translate existing physical geometry to the digital model. Rather than a position of a generic or previously defined geometry, the actual 3D representation of the model is transmitted, processed and visualized by the component. The system implementation supports a wide array of physical models, ranging from extruded blocks (represented as planar

surfaces and heights) to free form shapes (represented as triangulated meshes). This opens up an entirely new range of possibilities of integrating physical models in a digital platform as users are not limited to any specific geometry and have much more design freedom being able to build any shape from any material and integrate it seamlessly into the digital setting. The technology is not limiting the freedom of the design but rather adds additional layers of information on top of it.

Figure 4
The Custom
Grasshopper3D
plugin, receiving
and reconstructing
3D information over
TCP/UDP in real
time, making it
available for further
manipulations in
Grasshopper and in
Rhino.



In order to accommodate for these requirements, together with the motivation to keep the configuration as fast and easy to operate as possible, it was decided to implement a single Grasshopper component. A TCP (for reliably establishing connections) and UDP (for streaming data once the connection has been established) client which was described in the previous section has been adjusted and maintains the live stream between the CDP platform and Grasshopper. An additional program was developed in order to create a bridge to a Grasshopper component (Figure 4) whose input parameters consist of the connection details, custom configuration settings and a Boolean flag allowing to turn live streaming of data on and off. The output parameters consist of the footprint surfaces and heights for extrusions and mesh geometry for free form shapes. A distinction is made between the physical and the digital geometry passed from the CDP platform. The physical would often correlate to the actual design while the digital to the surroundings. That separation is particularly important

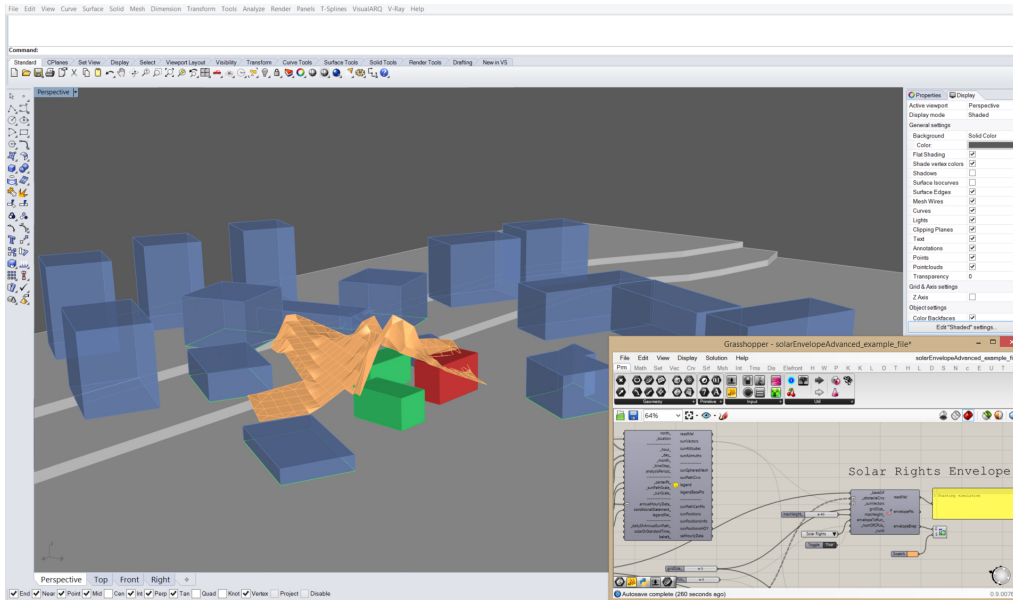


Figure 5
A custom Solar rights envelope simulation component in Grasshopper showing an urban context and a 3D polysurface representing maximum heights which new development should not exceed in order to not block direct sun access.

when running simulations where a clear distinction between the context which is fixed and the design which is subject to change.

Once data is received and processed by the Grasshopper component, it is available for the vast array of manipulations and simulations which exist either natively in Grasshopper or in custom plugins. Though most of the development focused on providing a generic solution to serve as a base for other Grasshopper definitions, several workflows, mostly in the field of climate simulations, have been developed further as test cases. These range from rather straightforward simulations such as shading studies up to radiation, energy use and outdoor comfort simulations. To better illustrate the proposed workflow, an implementation of a solar rights envelope simulation based on the method proposed by Capeluto and Shaviv (2001) which determines the maximum height of new development in a site while preserving direct sun access to surrounding buildings is presented (Figure 5).

The process begins as a digital model is loaded to the CDP platform and is extended with physical objects. Once the Grasshopper plugin has been configured to the IP address and port of the CDP platform a live stream first constructs the combined model in Grasshopper and then responds in real time to changes made to the model. From this point data is available for further manipulations in Grasshopper.

The solar rights plugin has several inputs- the geometry on which solar access is tested on, the geometry which potentially blocks solar access, and configuration settings such as grid size and sun positions tested upon. The output is a polysurface representing the maximum heights of the new buildings which would still preserve solar access to the surroundings.

The polygons of the surrounding buildings are chosen and their facades are extracted and passed to the solar rights plugin as is the geometry of the physical objects. The other settings are preconfigured and can be optionally overwritten for advanced usage. Once the simulation is set to run, a polysurface ap-

pears in a certain relation to the new development and another component checks for an intersection between the physical buildings and that polysurface. If intersections exist, meaning there is a height deviation, the new buildings that are harming the solar access rights of the existing ones are colored red, allowing for an intuitive way to identify the problematic areas. Anytime the physical objects are removed, added or moved, the simulation is re-triggered and the results are updated in real time, creating a constant feedback loop which helps to inform and improve the design in real time.

SUMMARY

The prototype presented in this paper allows for direct control of digital geometry in Grasshopper 3D using tangible interfaces. Due to the seamless connection of physical models and digital content, physical models of urban design strategies can be analyzed directly in Grasshopper. One of the notable advantages of the proposed method relates to the tangibles, serving not only as placeholders in a Grasshopper and a Rhino scene, but are free form physical objects which are digitally reconstructed and allow for further analysis and simulation tools from Grasshopper to be directly used in a physical model. In addition parametric relationships can be programmed in grasshopper and be controlled by the tangible interfaces. One of the challenges at the moment concerns the high computation time of some analyzes. Furthermore, in order to accurately conduct some of the mentioned simulations, more detailed information which is usually not known during the early design stages must be supplied. Besides urban scenarios other forms of usage for parametric design in Grasshopper are conceivable, as any form of placed objects on the table can be used directly as a starting point for digital manipulations.

FUTURE DEVELOPMENT

One area of further research revolves around the development and incorporation of tools to quickly evaluate thermal and visual outdoor comfort in the pub-

lic realm. Such research will focus on simulating microclimate and spatial comfort maps. An additional area of development concerns visualization of simulation results. Currently the visualized results are presented on screens as perspective, side views and a juxtaposed top view incorporating the digital and the physical model. As the method described in this paper tries to simplify the design process and make it more intuitive and tangible, two further visualization techniques are being developed:

1. Projecting the results of the simulations on the facades of the physical model in addition to the 2D visualization.
2. Incorporating augmented reality techniques.

The proposed approach opens up new possibilities for the early stages of design and decision making process. This is achieved by offering an intuitive and collaborative tool with which architects, urban planners, community leaders and policy makers are able to simulate and evaluate implications of design decisions in the urban and neighborhood scale in the ongoing attempt to create healthier, sustainable and livable cities.

REFERENCES

- Capeluto, I.G and Shaviv, E 2001, 'On the Use of Solar Volume for Determining the Urban Fabric', *Solar Envery*, 70, pp. 275-280
- Crawley, DB, Pedersen, CO, Lawrie, LK and Winkelmann, FC 2000, 'EnergyPlus: Energy Simulation Program', *ASHRAE Journal*, 42, pp. 49-56
- Fjeld, M, Lauche, K, Bichsel, M, Voorhorst, F, Krueger, H and Rauterrberg, M 2002, 'Physical and Virtual Tools: Activity Theory Applied to the Design of Groupware', *Computer Supported Cooperative Work*, 11, pp. 153-180
- Goldschwendt, T, Anthes, C, Schubert, G, Kranzlmüller, D and Petzold, F 2014 '[DEMO] The Collaborative Design Platform Protocol: A Protocol for a Mixed Reality Installation for Improved Incorporation of Laypeople in Architecture', *Proceedings of the International Symposium on Mixed and Augmented Reality (ISMAR)*
- Guglielmetti, R, Macumber, D and Long, N 2011 'OPEN-STUDIO: An open source integrated analysis platform', *Proceedings of the 12th conference of interna-*

- tional building performance simulation association, Sydney,, pp. 442-449
- Kalay, YE, Khemlani, L and Choi, J 1998, 'An integrated model to support distributed collaborative design of buildings', *Automation in Construction*, 7, pp. 177-188
- Penn, A, Motttram, C, genSchieck, AF, Wittkämper, M, Störing, M, Romell, O, Strothmann, A and Aish, F 2004, 'Augmented Reality Meeting Table: a Novel Multi-User Interface for Architectural Design', in Leeuwen, Jos P. Van and Timmermans, Harry J.P. (eds) 2004, *Recent Advances in Design and Decision Support Systems in Architecture and Urban Planning*, Springer, pp. 213-231
- Rahmawati, Y, Utomo, C, Anwar, N, Setijanti, P and Nurcahyo, CB 2013, 'An Empirical Model for Successful Collaborative Design Towards Sustainable Project Development', *Journal of Sustainable Development*, 7, pp. 1-14
- Reinhart, CF, Dogan, T, Jakubiec, JA, Rakha, T and Sang, A 2013 'UML- an urban simulation environment for building energy use, daylighting and walkability', *Proceedings of BS2013*, Chambéry
- Reinhart, CF and Walkenhorst, O 2001, 'Dynamic RADIANCE-based Daylight Simulations for a full-scale Test Office with outer Venetian Blinds', *Energy and Buildings* 33, 33, pp. 683-697
- Roudsari, MS and Pak, M 2013 'Ladybug: a parametric environmental plugin for grasshopper to help designers create an environmentally-conscious design', *Proceedings of BS2013*, Chambéry
- Salim, FD, Mulder, H and Jaworski, P 2010 'Demonstration of an Open Platform for Tangible and Social Interactions with Responsive Models', *ACADIA 2010*, New York,, pp. 227-233
- Schubert, G 2014, *Interaction forms for digital design: a concept and prototype for a computer-aided design platform for urban architectural design scenarios*, Ph.D. Thesis, Technical University of Munich
- Schubert, G, Artinger, E, Petzold, F and Klinker, G 2011 a 'Bridging the Gap: A (Collaborative) Design Platform for early design stages', *Proceedings of eCAADe 2011*, Ljubljana, pp. 187-192
- Schubert, G, Artinger, E, Petzold, F and Klinker, G 2011 b 'Tangible tools for architectural design: seamless integration into the architectural workflow', *Proceedings of ACADIA 2011*, Banff, pp. 252-259
- Schubert, G, Riedel, S and Petzold, F 2013 'Seamfully connected: Real working models as tangible interfaces for architectural design', *Proceedings of 15th International Conference, CAAD Futures 2013*, Shanghai, China, pp. 210-221
- Underkoffler, J and Ishii, H 1999, 'Urp: A Luminous-Tangible Workbench for Urban', *proceedings of the SIGCHI conference on Human Factors in Computing Systems*, 1, pp. 386-393
- Viola, A and Roudsari, MS 2013 'An innovative workflow for bridging the gap between design and environmental analysis', *Proceedings of BS2013*, Chambéry, pp. 1297-1304
- Ward, G and Shakespeare, R 2004, *Rendering with RADIANCE. The Art and Science of Lighting Visualization*, Booksurge Llc
- Weytjens, L, Macris, V and Verbeeck, G 2012 'User Preferences for a Simple Energy Design Tool: Capturing information through focus groups with architects', *28th PLEA Conference*, Lima
- [1] <http://diva4rhino.com>