CAD integrated workflow with urban simulation-design loop process

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Abstract

The urban space nowadays is considered as an aggregate of large amount of complex characteristics. Information collected by means of urban big data approaches play a crucial role in how to understand, interpret and model urban environments. Simulation models are the best solution for architects, urban planners and designers to integrate various information about urban complexity into the design process. The connection between several simulation approaches within one user interface is still a big challenge to make the design process faster, more accurate and visually convenient. The interface would be involved in the modelling process, pre-processing, simulation, post-processing and visualisation. A CAD integrated user interface is proposed where all these particular components are embedded into one system. The whole process would be based on a workflow loop whereby each component will be depending on the previous cycle. As a case-study of such a principle we establish an extendable modelling and simulation platform connected to a user through the game-engine Unity3D in order to achieve a robust interactive environment. The model platform operates with real urban conditions of an existing part of the city of Singapore and simulates the distribution of traffic's heat within the investigated environment. Based on the simulation results the user can configure more proper spatial scenarios within the urban plan in different variations. The proposed system would help architects and urban planners to enhance their decision repertoire during the design phase and allows them taking into account more complex information about the urban entirety. The result of the research is therefore a computational decision-making tool with enhanced visual output.
Keywords: CAD integrated urban simulation, urban modelling workflow, simulation-design loop, multi-simulation user interface, simulation integration, UNITY3D engine, interactive urban modelling.

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1 Introduction: simulation models in urban complexity

1.1 Big data in urban modelling

The term big data will be used here in two different ways. First to describe the huge amount of data and information available about the built environment, which helps us understanding the historic and larger concept of a city, whereby the environmental behaviour, population data, infrastructure data, vegetation and other related data can be combined to use for architects, urban planners, designers or other government body in order to setup the guidelines for further consideration in a decision making processes regarding the improvement of the public urban space. Secondly, big data is a data acquisition approach, rather tapping public available sources (e.g. online or meta data from social platforms) and using the crowd (of citizens) to provide input.

1.2 Motivation

This paper will use one case study, exemplary for the framework of the big data approach. In particular it will deal with the anthropogenic waste heat from traffic and its distribution within the urban environment in order to simulate the micro-climatic conditions in selected areas of Singapore. Such an observation will yield visual and understandable information about heat and thus outdoor thermal comfort within the investigated areas and would serve as a base for further consideration during the planning process in terms of improvement of the urban environment. Understanding the traffic's urban heat emissions as a significant issue in the tropical cities, the planning and decision-making processes should became a legitimate part of the particular zooning processes.

Simulation and modelling gets a different meaning if you look at it from another perspective. We worked closely with engineers from TU Munich at the TUM CREATE office in Singapore, where they study electric mobility. Their teams on simulation of agent-based transport on macro scale and on the car's component-based model together with the modelling and optimization group provided the background data in terms of vehicle-related input to our simulations and models in CAAD.

2 Simulation-design loop workflow

There are varieties of information which need to be considered and involved into the design process. A flexible data exchange, as we propose, between various simulation approaches within one integrated system can influence the design proposal more efficiently rather than conventional design process with different software toolsets that provide wide range of single top-down outcomes.

2.1 Workflow definition

This integration of complex information into the design workflow would yield a successful decision-support medium in the selection of an appropriate design scenario, driven by customized simulation platforms. In that manner design alternatives are tested in each iteration within a simulation looping process that can be run several times and receives direct feedback from the user (Figure 1A). However in this context several questions remain to be answered: How to integrate in a convenient way a variety of customised simulation and analysis platforms

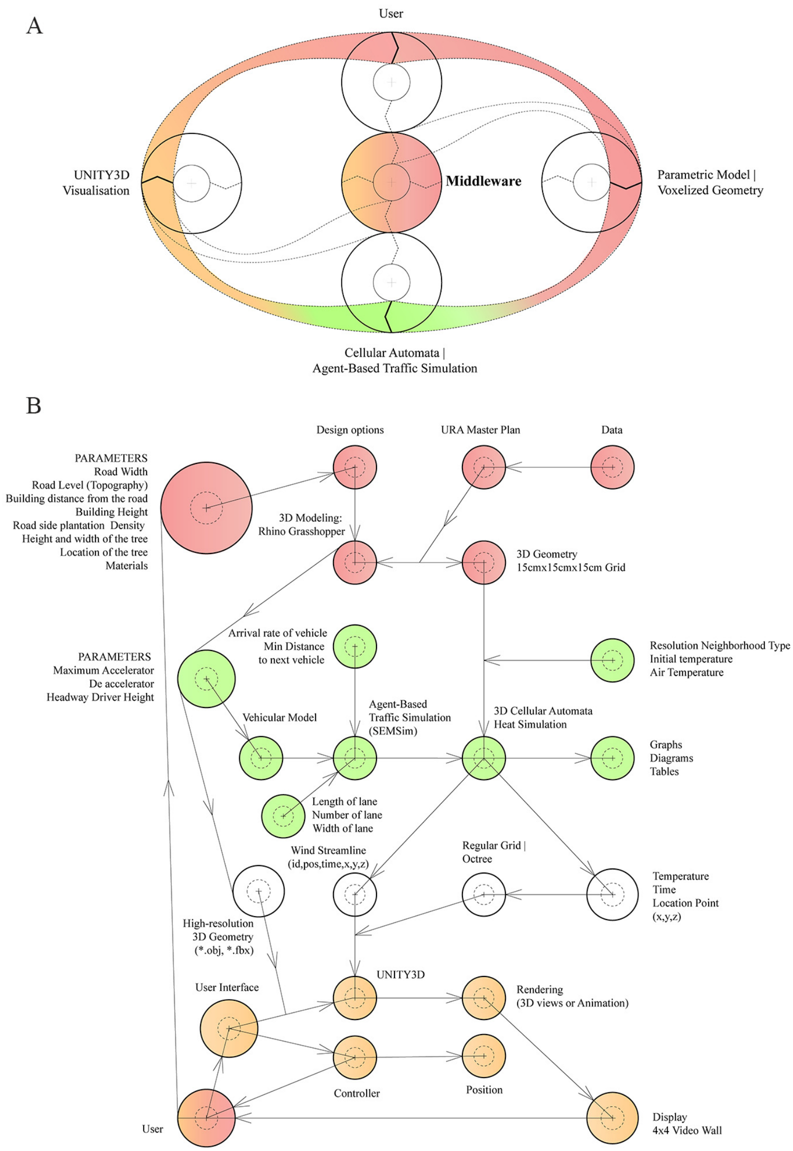

Figure 1: A) Workflow of iterative simulation-design loop. B) Data flow diagram within the whole simulation-design loop process.

with a CAD modelling environment into one system? How is it possible to efficiently evaluate design alternatives in a visual and interactive user-interface, even on a real time basis? How can user interact and interoperate with such a robust environment? In the intention of a framework where a design environment that supports interaction by engaging a data and cooperation strategy for exchanging information between particular parts in the workflow, [1, 3] we propose a CAD integration of urban simulation into one looping interactive process. The system would provide results outside the BIM-based design environments and turns to a fully serviceable, extendable and scalable parametric modelling interface with direct (and interactive) user inputs and control in a full customized environment.

2.2 State-of-the-art platforms

Many workflow systems are existing nowadays, with different functionalities covering a wide range of scientific disciplines. In the context of architecture a system, DEEPA is currently being developed by Toth *et al.* [2] as an integrated Generative Components plug-in in terms of energy simulation design support tool focused on a building scale and its energy efficiency. Similarly, many simulation systems have been developed so far as add-ons for the Grasshopper software, with different levels of interactivity and the design support feedback focussing more on building scale. Grasshopper add-ons developed by Roudsari [4], such as Ladybug or Honeybee [5], provide an almost instantaneous feedback on design modifications, however operate with a very straightforward workflow base and data format. The urban information modelling and simulation platform provided by Aschwanden *et al.* [6] uses procedural modelling upon a GIS-database in order to achieve generated rule-based 3D geometry within CityEngine environment. This system is clearly structured and operates with precise datasets. However, it provides a single geometric solution only with lack of direct feedback onto the design process. As well it uses different specific application for each type the simulation is executed.

2.3 Iterative simulation-design loop

This paper is rather focused on the observation of the potential integration of custom-based urban simulations and tools into one parametric visualisation environment as an adaptable and scalable system. In particular, the research concentrates onto simulation models in an urban scale integrated into Rhino/Grasshopper, driven by a user connection based on Unity3D's game-engine system, which shall be a fully interactive and open-source environment. The overall process in principle is demonstrated on Figure 1B. The simulation and design process will take into account openness for multi-scale urban information based on GIS/CAD data transformed into a parametric representation whereby the user is allowed to modify various geometric parameters in the model via a graphical user interface, e.g. Aschwanden *et al.* [6]. The middleware system has been established within the Grasshopper application as a user-defined parametric 3D modeller and connection, and furthermore as a data converter platform between external simulations. This is based on data exchange in a pseudo-real time process of dataflow. Grasshopper is a visual programming tool which allows the user to implement various parameters into the model and keep the modelling history still accessible during the whole modelling process. The simulation itself is a custom-based process developed in Python language as an external source. The simulation results are written into a datasets in a post-processing step, and can later be visualised in the Unity3D system. The connections of the data flows in the whole process and between particular parts are represented in the workflow diagram, Figure 1B.

3 Case study simulation model scenario specification

A case study of a specific simulation scenario has been created in order to observe simulation-design loop process with the visual outcomes. As such, a selected part of Singapore has been considered into the framework of the simulation process, Figure 2.

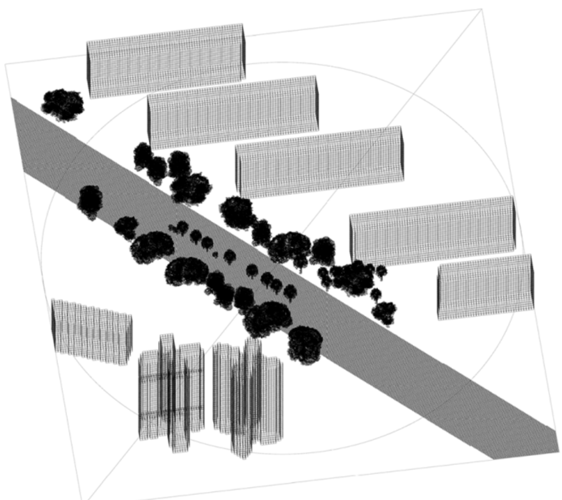

Figure 2: Axonometric diagram of the investigated part of the Ayer Rajah expressway (AYE) in Singapore, 1°18’44.0” N 103°45’44.8” E, scale 1:4300.

There is a long-term issue of the traffic heat and traffic noise occurrence in tropical cities which directly and negatively affects the comfort and quality of the urban area in terms of comfortable liveable place [7, 8]. This paper is focused on the heat distribution issue within the city environment located at the AYE road nearby Clementi district in Singapore. The aim of the simulation is to understand how the traffic heat is distributed within the local city space in order to find an appropriate way how to improve the spatial qualities and environmental conditions of the investigated environment. The selected part represents a typical urban situation which consists of the main traffic road surrounded by green vegetation and housing settlements. The high-resolution 3D model of the selected area has been prepared for the simulation in a geometric base. The simulation contains an agent-based traffic definition of the car movement in the 100 meters long route based on SEMSim application definition from the TUM CREATE. The traffic's heat distribution is modelled by means of cellular automata representation (CA) as an appropriate simplification of the dynamic urban phenomena simulated by Wagner *et al.* [9]. 3D cellular automata are used as well as an appropriate visual representational form of urban heat distribution taking into account the spatial and physical conditions of the selected area. In that way CA are capable to simulate the heat distribution even through the air. The middleware platform defined in the Rhino/Grasshopper application serves as a main data communication channel between the particular parts of the whole simulation process.

4 User-defined interface-middleware platform

The middleware is established as a parametric 3D modeller and it serves as a data connection between the geometric 3D model of the investigated area, the agent-based model, and the cellular automata in a single simulation platform.

The data flow principle within the middleware platform is represented by the diagram in Figure 3. The parametrization of the 3D model yields an advantage of the fast remodelling process for different spatial scenarios of the area.

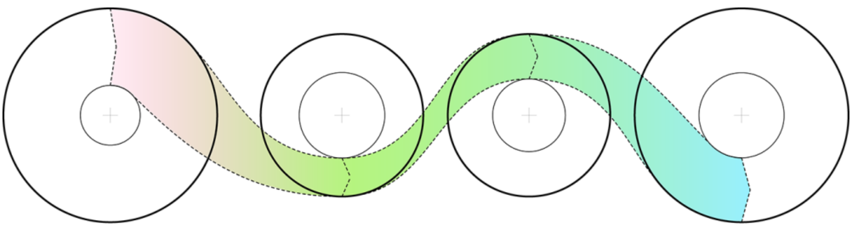

Figure 3: Systemic diagram of modelling process in the framework of the established middleware system.

By means of Grasshopper the user is allowed to specify geometric characteristics of each building parametrically – number of floors, construction height, sizes, etc. as in Figure 4. It is possible to define properties of the investigated part of the road – number of lanes, height level, size of the each lane and pavement, size of the green area alongside the road and establish the tree library into database within the model with various properties-height, type, number of trees and the size of the populated area by the trees, see Figure 5. For the cellular automata simulation one can transcript the high-resolution geometry into the simplified voxelized representation in order to define a base for CA simulation, Figure 6. The model allows user to re-write its 3D geometry into CSV data structures.

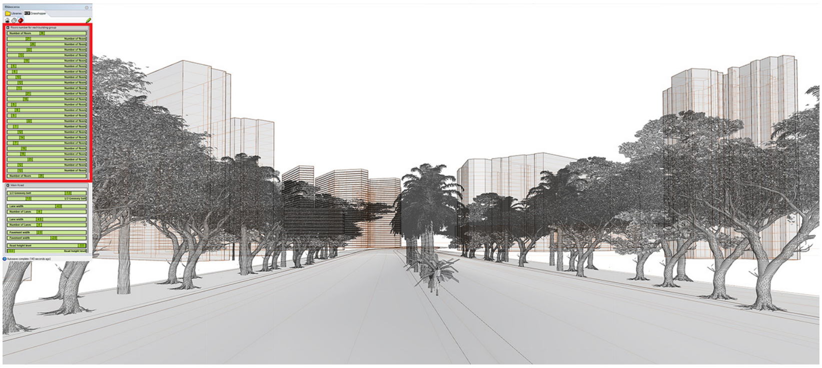

Figure 4: Parametrically user-defined geometry of buildings. User interface with a control panel. Parameter sliders regarding the number of floors are highlighted in red.

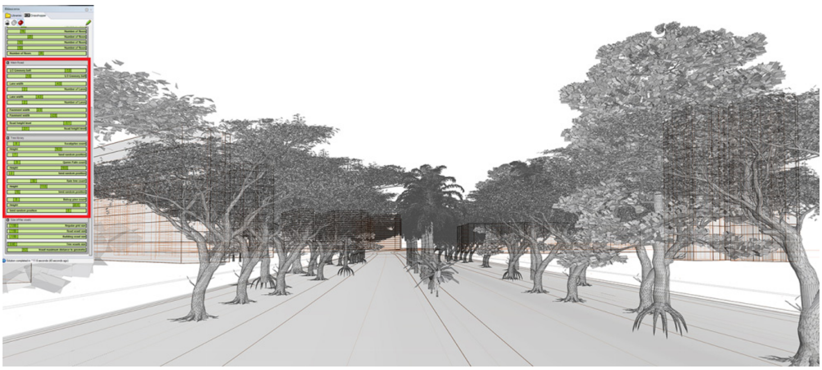

Figure 5: Parametrically defined geometry of the main road and the tree library.

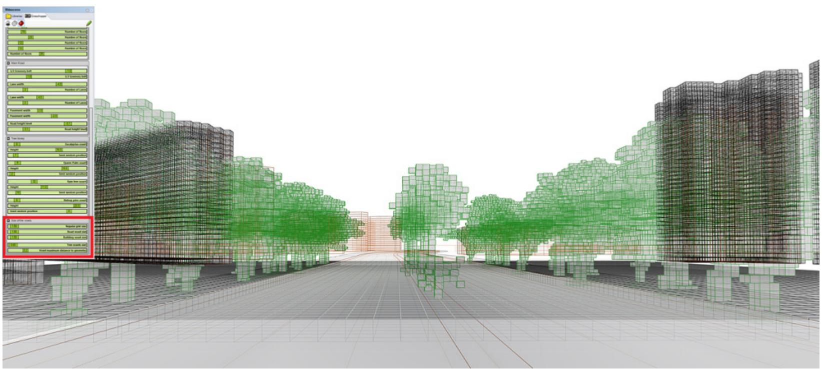

Figure 6: Scenery after voxelisation process-base for the CA simulation pre-processing. It is possible to specify the resolution of the voxels for each part of the model.

The parameter control regarding the geometric characteristics of the particular parts in the 3D model is accessible via a remote control panel within the graphical user interface directly in Rhinoceros application.

Once the geometry is specified and an appropriate spatial scenario is chosen, the algorithm will accomplish a voxelisation of the geometry for the further CA simulation. Each voxel's centroid point is written into the CSV dataset defined by its XYZ coordinates. The route specification in the model is exported into XML data structure for further implementation into the SEMSim application. Hereafter, an Octree algorithm divides the original cell size into smaller parts down to the size of 15 x 15 x 15 cm during the simulation process. In that manner it is possible to simulate the urban heat in a high-resolution CA representation with a precision according to the vehicle scale [7].

5 Interactive visualisation environment

Unity3D as a virtual environment plays the role as a bridge between simulation result and user feedback in terms of incorporation of various data into one platform. It serves as a medium for performing visual-based analysis in the early stage of the design process [10, 11]. As such, the game-engine environment is a part of the simulation design loop whereby visually and dynamically represents thermal environmental qualities, like in Stone *et al.* [12] or Berger and Cristie [13]. While users are allowed to change the 3D geometric model using Rhino/Grasshopper, this decision will usually be made after the exploration which they have done in the visualisation environment. This interactive visualisation environment developed using Unity3D is called *Visualizer*, Figure 7.

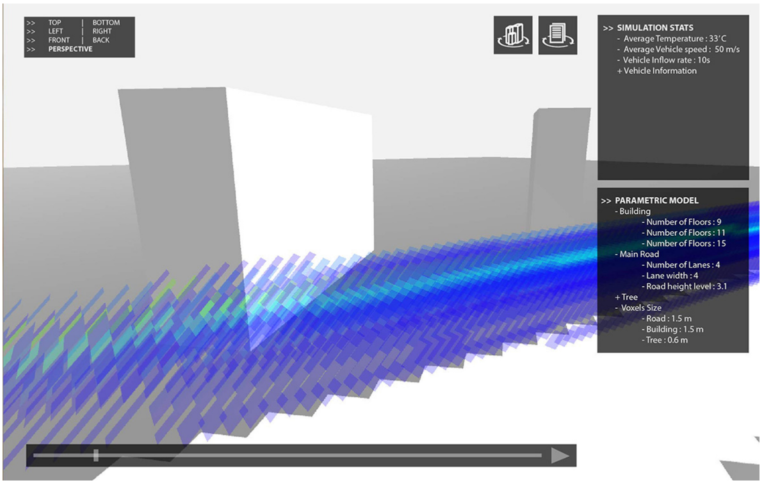

Figure 7: Visualizer overview.

Users will start by loading simulation results and the parametrical 3D model. Both are loaded separately, each with its own load button that will pull the data upon clicking. The 3D model's data is taken from in specific OBJ files in the system, and the simulation result data is taken from specific text files in the system. Information panels are displayed to show numeric values of simulation result and the parameters of the 3D model. In the current implementation, simulation result data is being loaded in a *SQLite* local database, to allow an ease query for visualization purposes.

After the data is loaded, the user is allowed to roam freely in the environment. The camera for the exploration can be moved forward/backward, left/right, and up/down and also rotated in X, Y, and Z axis. Shortcut function allows user to immediately see the view from top, bottom, left, right, front or back of the environment. The viewing range of the data can be adjusted based on user's position in the environment, to avoid cluttering of data. Several data filters will also be implemented, so that user will be enabled to gain insightful knowledge from the visualisation, Figure 8.

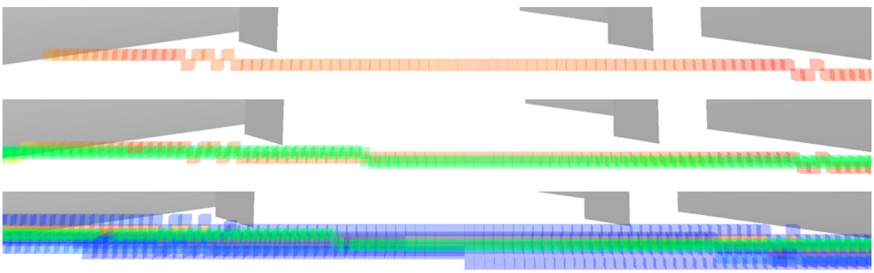

Figure 8: Filtering of temperature data.

As the heat simulation is performed using the CA model in the Octree algorithm, the *Visualizer* is able to show data at different level of details – from the most coarse to the finest level of the Octree. An animation scrollbar with play/pause button allows the user to observe how the heat is distributed throughout the time, Figure 9. Users can furthermore use the scrollbar to choose a specific point of time they are interested in.

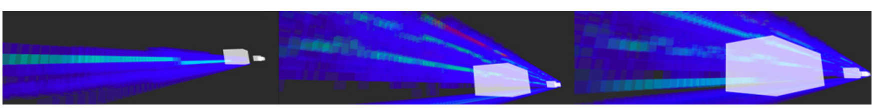

Figure 9: Visualisation at different time steps.

6 Simulation informed urban design

The simulation process presented in the framework of connecting Rhino/Grasshopper and Unity3D allows the user to modify the geometric urban model intuitively, within the middleware system, based on specified parameters. Taking into account the simulation results one can have a direct insight into the heat distribution within the urban area, and one is able to modify the spatial characteristics, e.g. vegetation size and its position, building characteristics or position according to the edge of the main road or geometry of the traffic route and therefore change the spatial character of the urban environment in order to achieve better results and conditions of environmental quality. As such, the built environment would potentially be better protected against urban heat (islands). Visual and spatial information about the urban heat within the urban environment yield answers not only about spatial reconfiguration of existing urban elements but offers an alternative idea about elimination of the motor vehicles in the city and replace them by more convenient solution (electric vehicles) with a direct, positive effect on environmental qualities.

7 Discussion and future work: extendable simulation and modelling tool

As the process has still certain limitations and is written in a pseudo real-time routine, the middleware system needs to be tested e.g. by usage of the UDP communication protocol by Fraguada [14] in real time interaction with Unity3D, in order to make the whole simulation-design process faster and more interactive. Current work focuses on implementation of a scalable data stream from simulation and geometry, such that an interactive frame rate is achievable. Measures on parallel processing (computing) and a more scalable database are possibly implemented.

On the other hand, the middleware is extendable and scalable modelling tool that can be updated in every characteristic and its functionalities can be advanced with new features. The integration of the Unity3D into the computer aided design connected with the simulation process as a visualisation and interactive tool makes whole process more convenient and visually understandable for the user.

Furthermore, one could look into implementation of a web architecture such that simulation result and geometric model data are stored in central database. Web API can be used by the simulation engine and Grasshopper to inform Unity3D whenever there is an update. Unity3D will query data from the database for visualisation.

8 Conclusion

The simulation-design loop system in the framework of Rhinoceros/Grasshopper parametric model, simulation and Unity3D applications have been established as a scalable and extendable modelling and simulation tool based on a pseudo real-time dataflow. The visual simulation result invites the user to further manipulations of geometry parameters within the middleware system, in order to obtain better spatial conditions of the urban environment when necessary. The open and extendable framework of the middleware tool allows urban planners to integrate various geometric characteristics of the investigated urban environment into the modelling process, and to send the datasets into various formats for further simulation and computing. By means of Unity3D it is possible to observe simulation results in the each step of the simulation-design loop process.

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References

[1] Toth, B., Salim, F., Drogemuller, R., Frazer, J. & Burry, J., Closing the loop of design and analysis: Parametric modelling tools for early decision support. Proc. of the 16th International conference on Computer-Aided Architectural Design Research in Asia, Circuit Bending, Breaking and Mending, eds. C. M. Herr, N. Gu, S. Roudavski & M. A. Schnabel, Association for Computer-Aided Architectural Design Research in Asia (CAADRIA): Hong Kong, pp. 525-534, 2011.

[2] Toth, B., Russell, A., Drogemuller, R., Frazer, J. & Salim, F., Sky high and back again: The evolution of simulation-based design from aerospace to construction. Proc. of Building Simulation 2011: 12th Conference of International Building Performance Simulation Association, IBPSA: Sydney, pp. 1229-1236, 2011.

[3] Toth, B., Boeykens. S., Chaszar, A., Janssen, P. & Stouffs, R., Custom digital workflows: A new framework for design analysis integration. Proc. of the 17th International conference on Computer-Aided Architectural Design Research in Asia, Beyond Codes and Pixels, eds. T. Fischer, K. De Biswas, J. J. Ham, R. Naka & W. X. Huang, Association for Computer-Aided architectural Design Research in Asia (CAADRIA): Hong Kong, pp. 163-172, 2012.

[4] Roudsari, M. S., Ladybug for Grasshopper, GitHub, Inc. Website, Online. https://github.com/mostaphaRoudsari/ladybug

[5] Roudsari, M. S., Ladybug + Honeybee, Grasshopper Algorithmic Modelling for Rhino Website, Davison, S., Online. http://www.grasshopper3d.com/group/ladybug

[6] Aschwanden, G., Zhong, Ch., Papadopoulou, M., Vernay, D. G., Arisona, S. M. & Schmitt, G., System design proposal for an Urban Information Platform. Proc. of the 30th eCAADe conference, Digital Physicality vol. 1., eds. H. Achten, J. Pavlicek, J. Hulin & D. Matejovska, Czech Technical University in Prague, Faculty of Architecture: Prague, pp. 665-673, 2012.

[7] Berger, M. & Aydt, H., Traffic and Heat – Using cellular automata to study the environmental impact of vehicle heat emissions. FCL Magazine, 3, pp. 14-21, 2015.

[8] Berger, M., Urban heat-balling, Proc. of Sustainable future energy 2012 and 10th SEE Forum, Green, Sustainable, Renewable, Efficient, Universiti Brunei Darussalam (UBD) Energy Research Group; Material Research

Cluster; Sustainable Energy and Environment (SEE) Forum; ASEAN University Network (AUN): Darussalam, unpaged, 2012.
[9] Wagner, M., Viswanathan, V., Pelzer, D., Aydt, H. & Berger, M., Cellular Automata-based Anthropogenic Heat Simulation. Proc. of the International Conference on Computational Science 2015, Computational Science at the Gates of Nature, eds. (forthcoming), Elsevier: Reykjavik, pp. (forthcoming), 2015.
[10] Indraprastha, A. & Shinozaki, M., The investigation on using Unity3D game engine in urban design study. Journal of ICT Research and Applications, 3(1), pp. 1-18, 2009.
[11] Indraprastha, A. & Shinozaki, M., Constructing virtual urban environment using game technology. Proc. of the 26th eCAADe conference, Architecture in Computro, Integrating methods and techniques, ed. M. Muylle, eCAADe & Artesis University College of Antwerp: Antwerp, pp. 359-366, 2008.
[12] Stone, R., Guest, R., Pahl, S. & Boomsma, C., Exploiting gaming technologies to visualise dynamic thermal qualities of a domestic dwelling. Proc. of the BEHAVE 2014 – Behavior and Energy Efficiency Conference, The University of Oxford: Oxford, unpaged, 2014.
[13] Berger, M. & Cristie, V., CFD Post-processing in Unity3D. Proc. of the International Conference on Computational Science 2015, Computational Science at the Gates of Nature, eds. (forthcoming), Elsevier: Reykjavik, pp. (forthcoming), 2015.
[14] Fraguada, L.; GHowl, Grasshopper Algorithmic Modeling for Rhino Website, Davison, S., Online. http://www.grasshopper3d.com/group/ghowl