# WorkerBEE: A 3D Modelling Tool for Climate Resilient Urban Development

Giovanni Nocerino[1] and Mattia Federico Leone[2(✉)]

[1] PLINIVS-LUPT Study Centre, Università di Napoli Federico II, Urban Climate Change Research Network, Napoli, NA, Italy

[2] Dipartimento di Architettura, Università di Napoli Federico II, Urban Climate Change Research Network, Napoli, NA, Italy

mattia.leone@unina.it

**Abstract.** Algorithm Aided Design (AAD) tools are increasingly used in architecture and urban design practice for their ability of integrating simulation components within conventional 3D modelling software. This allows to run complex calculation models, managing data and assessing the effects of planning and design decisions in real time while developing the project. In particular, the modular nature of AAD tools allows to incorporate diverse elements and data [1], which can offer a valuable support to researchers and practitioners in integrating the multidimensional performance indicators linked to the emerging concept of climate resilient development [2] within urban projects and evaluate the impact of design solutions.

This paper presents the first version of WorkerBEE: a 3D configurator and simulation tool developed in the context of the research activities conducted by the Urban Climate Change Research Network and University of Napoli Federico II (Department of Architecture and PLINIVS-LUPT Study Center) supporting district to neighbourhood scale urban microclimate analysis and multi-scale performance-based design. The tool aims at optimising and simplifying planning and design choices by integrating key performance indicators related to climate benefits (mitigation, adaptation) and co-benefits (social, economic, environmental) of solutions. The implementation of computational simulation engines allows to dynamically investigate the effects of design choices on the urban microclimate from the earliest conceptual stages, and consequently to evaluate different design alternatives with respect to the objectives to be achieved.

**Keywords:** Algorithm aided design · Climate resilient development · Multi-scale urban design

## 1 Introduction

### 1.1 3d Modelling and Computer Programming for Climate Resilient Design

The work presented in this paper is set in the broader context of computational design, and, in particular, aims to investigate how the implementation of "user friendly" computer programming languages in 3D modelling tools can support performance-based design and decision making processes for climate resilient design solutions.


F. Calabrò et al. (Eds.): NMP 2024, LNNS 1189, pp. 16–26, 2024.
https://doi.org/10.1007/978-3-031-74723-6_2

The instrumental and methodological capabilities linked to the digital innovations and the information revolution make it possible to achieve results that were precluded a few years ago: in fact, architecture, urban planning and design are becoming increasingly dependent on computation, intended not only as a medium for the representation of complex images [3]. Compared to the pre-digital era, where project outcomes were mainly determined by the designer's ability to come up with technological solutions that could only be communicated through traditional methods, the contemporary approach to design has evolved into a complex networked workflow. This workflow involves selecting geometric, spatial, technical, and economic information through simulation, analysis, and optimization processes [4].

Information technologies have therefore revolutionized the concept of the model in drawing. Previously, digital tools used for architectural design focused mainly on the morphological aspect and had specific interfaces for drawing. However, today's need for greater technical and informative control has led to an evolution of both the tools and interfaces.

In this context, simulation tools stand for their relevance. In general, computational simulation tools consist of a set of mathematical equations and theoretical principles derived from the phenomenon to be simulated, to which one or more parameters and indicators are associated. Parameters and mathematical principles are then processed into algorithms that can be calculated through software; the execution of these algorithms over a time interval constitutes the simulation of the system studied [5].

In the field of architecture, professionals and researchers, particularly those using a performance-based design approach, increasingly rely on computational simulation tools in order to optimize design solutions at different scales [6]. This approach involves using calculation results to inform the model directly, rather than nalyzing the performance of a given design solution through a separate tool and modifying it accordingly.

In addition to the increasing use of simulation tools, information technology has made a significant contribution to design through the integration of programming languages. This integration has led to the development of new design methods that rely on algorithmic support. These methods, known as algorithm-aided design (AAD), enable dynamic operation with diverse data, which can inspire new compositional ideas and draw attention to innovative design processes [7].

Integrating conventional computer-aided design (CAD) tools, like 3D modelling software with computational simulation tools and advanced AAD tools can provide valuable support for designing buildings and open spaces that are resilient to climate change, simultaneously controlling performance criteria linked to both CO2 emissions reduction and adaptation. One advantage of using these tools is the ability to import and manage various sets of data and process them in a single workspace. The model produces a graphical output and the associated information that changes based on the parameters defined by the designer, influencing both morphological and technological characteristics of the project.

To support climate resilient design, 3D models can incorporate both quantitative and qualitative data, linking them to the project's environmental and energy performances. This enables effective investigation of the effects of design choices on the urban microclimate from the earliest conceptual stages using computational simulation engines.

Different design alternatives can then be evaluated according to targeted performance benchmarks.

This paper introduce WorkerBEE, a 3D modelling method developed to support urban microclimate analysis and multi-scale performance-based design, from district to neighborhood and building scales, simplifying and streamlining data management and performance simulation processes. The tool was developed as part of research conducted by the Urban Climate Change Research Network (UCCRN) [8] and the University of Naples Federico II (Department of Architecture and PLINIVS-LUPT Study Center) in the context of the Horizon Europe projects KNOWING [9] and UP2030 [10].

## 2 WorkerBEE: The 3D Neighbourhood Configurator Tool

### 2.1 3D Modelling and Simulation Tools Interoperability Issues: The WorkerBEE Concept

Interoperability in the construction sector is a broad and complex concept that can cover both general areas of expertise and very specific areas where standard formats like the IFC are not sufficient to trigger a dialogue between different competences. This happens, for example, in energy simulation, quantity take-off, maintenance management, and site simulation [7]. For this reason, research in the field of IT technologies applied to design has been searching for new ways of information exchange and software interoperability, using other open formats (such as GBXML) or exchange processes based on algorithms. In this regard, Visual Programming Language platforms (VPL) are becoming increasingly important. Among these, the most widely used in the field of architecture is Grasshopper 3D, a visual algorithm editor integrated into the Rhinoceros modelling software (McNeel), which facilitates algorithm programming even for non-experts, effectively supporting AAD methodologies and interoperability with external simulation tools. This not only allows the optimisation of operational workflows, but also overcomes several "pedagogical" limitations [3, 11] imposed by the use of traditional simulation software, which are in fact «monolithic and isolated tools that often limit the modeller's learning process and can prevent him from achieving a deeper understanding of the components and assumptions of a computer simulation [12].

Nevertheless, the purely instrumental aspect of the link between 3D modelling tools and simulation software still has many limitations. One of the most important of these is undoubtedly the computation of time involved in managing the geometries of the simulation engine [13, 14], which has the main consequence of slowing down the design workflow. While the 3D modelling software are able to handle very complex shapes in a simple and fast way, simulation engines are not always optimised in this sense. In other words, most of these tools are able to work effectively when the models to be calculated are geometrically simple; conversely, large models composed of very complex geometries can lead to calculation times that are longer than necessary or even to the failure of the simulation.

However, in professional practice, simple 3D models with few details are mainly used in the very early stages of concept and mass modelling, where not all the necessary information is always available for simulation. Therefore, in order to achieve an optimised climate-resilient design workflow, it is important to find the right balance between the amount of technical and geometric information that needs to be fed into the performance calculation tools. For this reason, it is necessary for practitioners to have adequate knowledge not only of building physics and environmental design, but also of the technical limitations of the links between modelling and simulation tools, whether established by traditional or innovative methods such as AAD.

Although the VPLs embedded in 3D modelling software are very useful in this sense, streamlining data management in the design process, it is also true that users without the necessary technical skills or knowledge of the fundamentals of environmental design may find it complex to develop an algorithm that effectively links geometric input to the various complex data involved.

In order to fill these gaps and to provide researchers and practitioners with a simplified tool for the management of data and geometries for performance assessment related to climate-resilient design, research conducted by UCCRN and the University of Naples led to the development of WorkerBEE.

WorkerBEE is a 3D modelling and information management environment designed to generate urban scenarios and evaluate their performance in relation to qualitative and quantitative indicators. The tool aims to facilitate the understanding of climate modelling and promote climate resilient planning and design. It assesses key performance indicators for climate resilience from the conceptual design stage, including building massing.

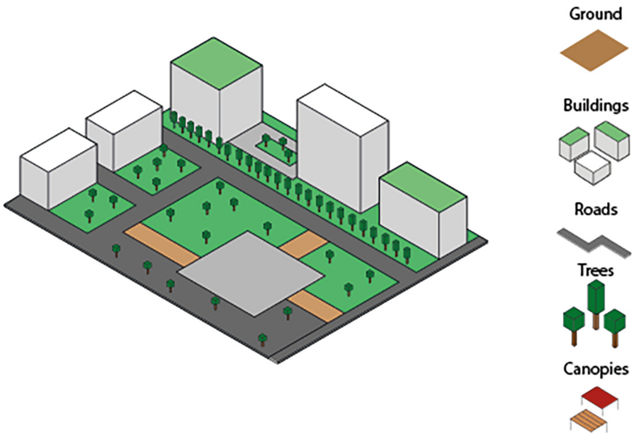


**Fig. 1.** WorkerBEE concept: configuration of urban spaces using simplified 3D objects

From a technical perspective, the tool comprises a series of components programmed in Grasshopper. Each component generates simplified and “blocky” 3D elements based on a specific set of parameters (Table 1) (Fig. 1). These elements can be easily handled in the Rhino workspace even by non-expert users: once all the elements have been generated, the user can combine them in the Rhino environment to create a simplified and schematic model of an open space. This allows for real-time monitoring of all essential information.

WorkerBEE operates in combination with the LadybugTools [15]. This allows for the simulation of various environmental and energy-related performances, establishing a direct link between Rhino and external validated engines such as Radiance or EnergyPlus +.

The 3D models generated by WorkerBEE automatically overcome the geometrical limitations of these engines and provide them with all the necessary input for running outdoor comfort and energy consumption simulations using specifically Honeybee and Dragonfly [16, 17] to establish the links. For this reason, WorkerBEE models can be used as a direct input for LadybugTools based algorithms, in order to obtain 3D visualisations of current city conditions and proposed design concepts.

## 2.2 Tool Operational Workflow and Outputs

WorkerBEE is still at its first stage of development and at the current state consists of five components: Ground Generator, Building Generator, Tree Generator, Road Generator and Canopy Generator. For each of these components the algorithm requires a set of inputs to generate the elements to "configure" the urban space (Fig. 2).

Each component is programmed as a Grasshopper Cluster containing specific Ladybug elements, novel custom Python components to assess additional environmental performances based on green building rating systems such as LEED and uses EleFront [18] components to assign information to every modelled object.

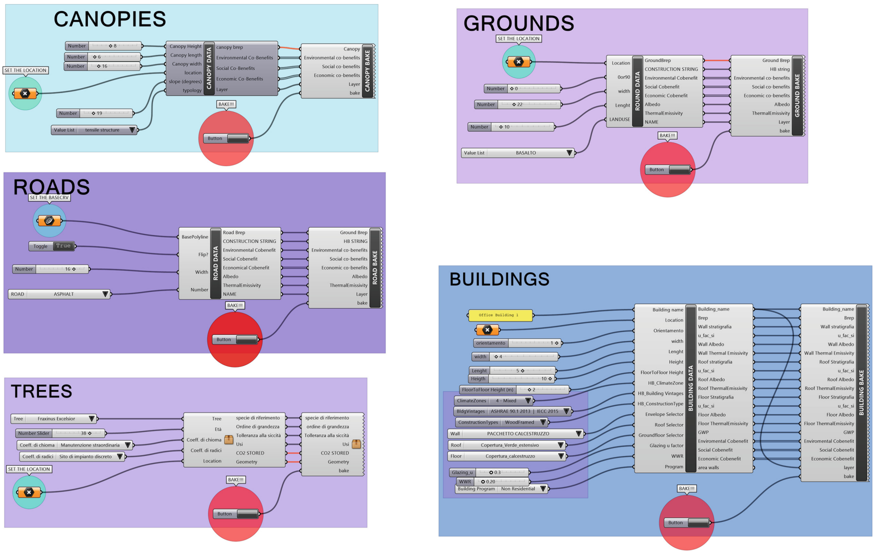


**Fig. 2.** WorkerBEE components in the Grasshopper environment

Each cluster has variable inputs that are essential for simulations. The operators can change these parameters based on their design choices, influencing the characteristics of the modelled objects. The tool's components have different outputs that vary depending on the inputs (Table 1). To simplify the modelling process, some of these inputs, such as the building envelope type, have several presets to choose from (Fig. 3).

Key quantitative performance indicators of the tool can be summarized as follows:

- Outdoor thermal comfort analysis
  - o Mean Radiant Temperature (TMRT) [°C]
  - o Universal Thermal Climate Index (UTCI) [°C]
- Indoor thermal comfort analysis
  - o Predicted Mean Vote [PMV]
- Energy analysis
  - o Energy Use Intensity [kWh/m2y]
  - o Renewable energy production potential [kWh/y]
- Carbon analysis
  - o Embodied carbon of building materials [$tCO_2$/ y]
  - o Carbon storage potential from vegetation [$tCO_2$/y]

Furthermore, potential social, economic and environmental co-benefits (e.g. public health, community inclusion, biodiversity increase, air quality increase, water quality increase) associated to the climate-resilient design solutions introduced are reported through an indexed scoring based on qualitative metrics.

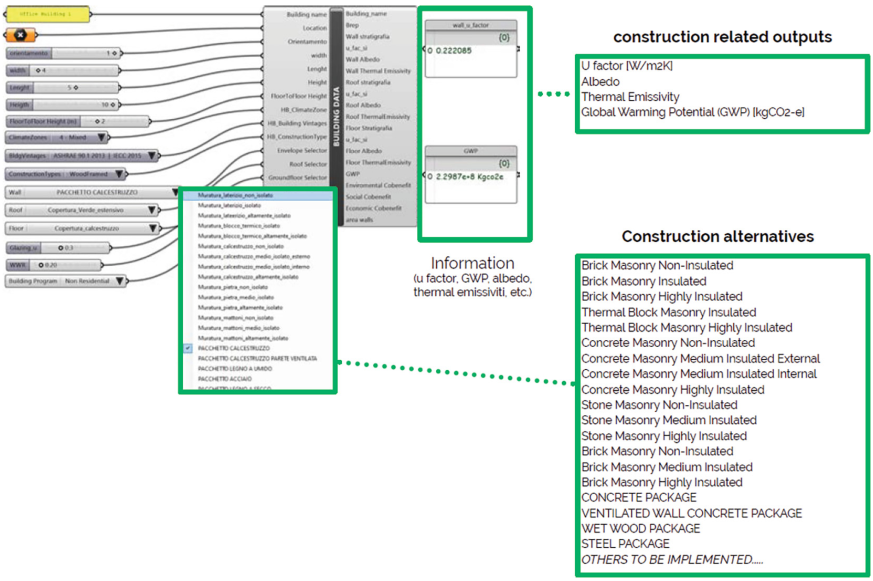


**Fig. 3.** Building Generator component: selection of the envelope type from the presets' library and outputs

**Table 1.** Overview of WorkerBEE components

| Component | Description | Inputs | Outputs |
|---|---|---|---|
| **Ground generator** | Generates a rectangular geometry representing the terrain shape. For each geometry the tool provides quantitative and qualitative information | • Geometry/dimensional information<br>• Landcover | • 3D shape<br>• Ground thermal features<br>• Environmental, social and economic co-benefits |
| **Building generator** | Generates a box geometry of the specified dimensions, which represents the building shape. According to the parameters the tool proves with information useful to outdoor comfort and energy simulations | • Geometry/dimensional information<br>• Envelope Construction<br>• Roof Construction<br>• Window Ratio (WWR)<br>• Bulding Age<br>• Program | • 3D shape<br>• Building envelope thermal features<br>• Embodied carbon of construction materials<br>• Environmental, social and economic co-benefits |
| **Tree generator** | Generates a box geometry of the specified dimensions, which represents the tree canopy | • Species<br>• Age<br>• Canopy maintenance status<br>• Terrain status | • 3D shape<br>• $CO_2$ stored<br>• Drought tolerance |
| **Road generator** | Generates a solid representing the shape of the road according to a given polyline and a number representing the width of the street. The tool provides different quantitative and qualitative information | • Geometry/dimensional information<br>• Landcover | • 3D shape<br>• Surface thermal features<br>• Environmental, social and economic co-benefits |

(*continued*)

**Table 1.** (*continued*)

| Component | Description | Inputs | Outputs |
|---|---|---|---|
| **Canopy generator** | Generates a rectangular geometry of the specified dimensions, which represents the canopy shape | • Geometry/dimensional information<br>• Typology (e.g.. Pergola, tensile structure, etc.) | • 3D shape<br>• Environmental, social and economic co-benefits |

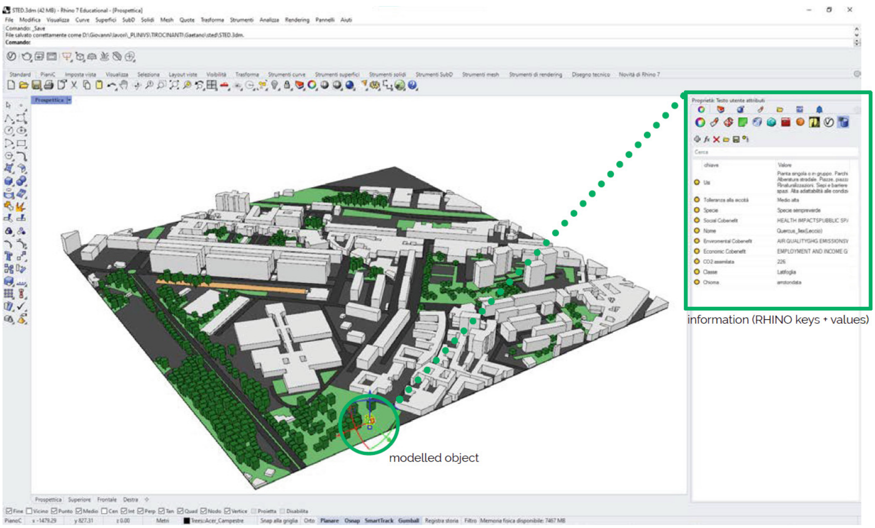


**Fig. 4.** Example of a 3D model generated using WorkerBEE with the set of information in the Keys and Values tab

After defining geometry and parameters of the objects to be modelled, the operator can generate them in Rhino with key performance indicators associated. The resulting objects include all the information resulting from the operator's choices, which are produced by WorkerBEE as output using Rhino's system of keys and values. An example of a typical 3D model obtained via WorkerBEE is shown in Fig. 4, where all output information for each selected element can be viewed in the Rhino keys and values tab.

## 2.3 Applications of Workerbee to Support Climate Resilient Design

WorkerBEE is highly flexible and effective in communicating with other algorithms programmed in Grasshopper, making it one of its main strengths. The Elefront plug-in used by the tool to associate and manage information makes it possible to establish direct and effective links between the generated model and external Grasshopper scripts, useful for carrying out evaluations and simulations of different environmental performances.

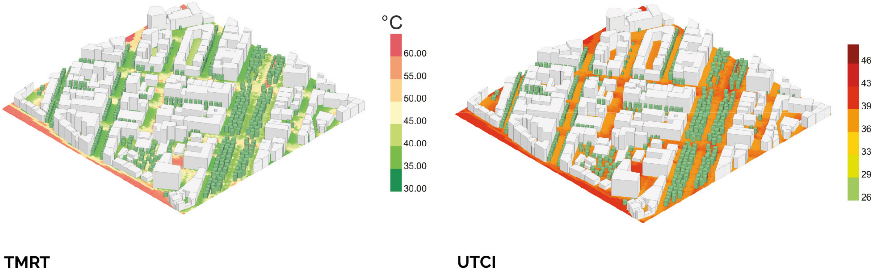


**Fig. 5.** Application of WorkerBEE in the Lisbon case study. Outdoor comfort analysis of current state scenario (Tmrt and UTCI indicators).

The research activities conducted by UCCRN provide an example of the effectiveness of this link. Specifically, in the context of the climate-driven Urban Design Climate Workshop (UDCW) methodology [19], which uses algorithms based on LadybugTools to simulate outdoor thermal comfort and energy consumption at the district scale (Fig. 5). Other UDCW tools comprises specific Grasshopper scripts to enable various types of analysis, including the evaluation of CO2 absorption by trees and the quantity of CO2 generated by building materials. The information contained in the 3D models generated

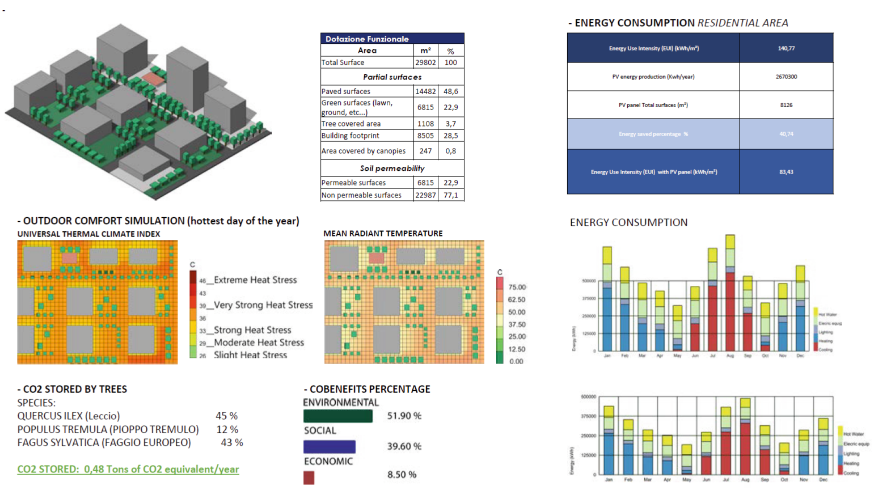


**Fig. 6.** Example of application and simulation outputs

by WorkerBEE, which is essential for the operation of these assessment tools, is loaded semi-automatically. Furthermore, the geometric simplicity of these models reduces calculation times, allowing for the rapid evaluation of different design alternatives. Figure 5 displays an example of output produced by the UCCRN simulation tools, which were fed by a 3D model provided by WorkerBEE (Fig. 6).

## 3 Conclusions

Workerbee is a tool that is currently under development. Its main objective is to simplify 3D modelling processes for environmental performance assessment in order to support performance-based design methodologies. The operation of this system is based on generating simple geometries and assigning them with essential information for various types of performance evaluations. This approach aims to address some of the main issues related to the implementation of simulation engines in 3D modelling and, more in general, in design workflows, particularly in the concept and mass modelling phases. Future implementations will aim to further simplify the modelling process and enrich the individual tools to expand the range of possible evaluations.

WorkerBEE components are designed to support the early design stages, where there is the specific need to quickly test different alternatives and design strategies. Typically, even when a consideration of climate, energy and environmental factors is given by planners and designers at this stage of the project process, only qualitative and descriptive information are usually introduced. This leads to the lack of control of critical urban climate factors [20] associated to morphological, technological and environmental design choices, which should be at the cornerstone of climate resilient development principles for planning urban design and architecture in the coming decades.

## References

1. Mackey, C., Roudsari, M. S.: The tool (s) versus the toolkit. In: Humanizing Digital Reality, Springer, Singapore, pp. 93–101 (2018)
2. IPCC.: Climate change 2022: Impacts, adaptation, and vulnerability. contribution of working group II to the sixth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 (2022)
3. Nocerino, G., Leone, M.F.: Computational LEED: computational thinking strategies and Visual Programming Languages to support environmental design and LEED credits achievement. Energy Build. **278**, 112626 (2023)
4. Russo Ermolli, S.: The Digital Culture of Architecture: note sul cambiamento cognitivo tra continuità e rottura, Maggioli Editore, Sant'Arcangelo di Romagna (RN) (2020)
5. Winsberg. E.: Science in the age of computer simulation, University of Chicago Press, Chicago (2010)
6. Oxman, R.: Digital architecture as a challenge for design pedagogy: theory, knowledge, models and medium. Des. Stud. **29**, 99–120 (2008)
7. Calvano, M.: Disegno digitale esplicito. Rappresentazioni responsive dell'architettura e della città, Aracne editrice, Canterano (RM) (2019)
8. Urban Climate Change Research Network (UCCRN). Available at: https://uccrn.ei.columbia.edu, last accessed 1/20/2024

9. KNOWING–Framework for defining climate mitigation pathways based on understanding and integrated assessment of climate impacts, adaptation strategies and societal transformation. Available at: https://cordis.europa.eu/project/id/101056841, Last accessed 1/20/2024
10. UP2030–Urban Planning and design ready for 2030. Available at: https://cordis.europa.eu/project/id/101096405, Last accessed 1/20/2024
11. Aish, R.: DesignScript: origins, explanation, illustration, Comput. Des. Model., pp. 1–8. (2012)
12. Mackey, C.: The Tool(s) vs toolkit: the hierarchical kit, In Naboni, E., Havinga, L. C. (eds.): Regenerative Design in Digital Practice: A Handbook for the Built Environment, Eurac, Bolzano, IT, p. 113. (2019)
13. Østergård, T., Jensen, R.L., Maagaard, S.E.: Building simulations supporting decision making in early design–A review. Renew. Sustain. Energy Rev. **61**, 187–201 (2016)
14. Solmaz, A.S.: A critical review on building performance simulation tools. Alam Cipta **12**(2), 7–21 (2019)
15. Roudsari, M. S., Pak, M.: Ladybug: a parametric environmental plugin for grasshopper to help designers create an environmentally-conscious design (2013)
16. Honeybee Primer, https://docs.ladybug.tools/honeybee-primer/, last accessed 1/20/2024
17. Dragonfly Primer, https://docs.ladybug.tools/dragonfly-primer/, last accessed 1/20/2024
18. Van Der Heijden, et al.:Parametric building information generation for design and construction. In Computational Ecologies: Design in the Anthropocene-35th Annual Conference of the Association for Computer Aided Design in Architecture, pp. 417–429 (2015)
19. Raven, J.: Urban Design Climate Workshops. In World Sci. Encycl. Clim. Chang.: Case Stud. Clim. Risk, Action, Oppor. **3**, 79–82 (2021)
20. Raven, J., Stone, B., Mills, G., Katzschner, L., Gaborit, P., Leone, M. F., Rudd, A.: Urban Planning and Design in UCCRN. In ARC3. 2 Assessment Report on Climate Change and Cities, (pp. 139–172). Cambridge University Press (2018)