



HAL
open science

Towards Context & Climate Sensitive Urban Design: An integrated simulation and parametric design approach

Aymeric Delmas, Michael Donn, Virginie Grosdemouge, Marjorie Musy,
François Garde

► **To cite this version:**

Aymeric Delmas, Michael Donn, Virginie Grosdemouge, Marjorie Musy, François Garde. Towards Context & Climate Sensitive Urban Design: An integrated simulation and parametric design approach. 4th International Conference On Building Energy & Environment 2018 (COBEE2018), Feb 2018, Melbourne, Australia. hal-01706655

HAL Id: hal-01706655

<https://hal.science/hal-01706655>

Submitted on 6 Apr 2018

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Towards Context & Climate Sensitive Urban Design: An integrated simulation and parametric design approach

Aymeric Delmas^{1,2}, Michael Donn³, Virginie Grosdemouge¹, Marjorie Musy⁴ and François Garde¹

¹ PIMENT - Physique et Ingénierie Mathématique pour l'Énergie, l'environnement et le bâtiment
Université de La Réunion, Le Tampon, 97430, Reunion Island

² CRENAU - Centre de Recherche Nantais Architectures Urbanités
Ecole Nationale Supérieure d'Architecture de Nantes, Nantes, 44000, France

³ School of Architecture
Victoria University of Wellington, Wellington, 6140, New Zealand

⁴ CEREMA Ouest - Centre d'Etudes et d'Expertise sur les Risques, l'Environnement, la Mobilité et l'Aménagement
Nantes, 44000, France

SUMMARY

Cities all over the world are redefining their urban landscapes with new buildings integrated within existing environments. Due to the dearth of climate and context consideration, as well as the lack of interoperability of existing design tools, buildings are mostly designed as stand-alone entities which limits their potential utilisation of natural resources and potentially affect existing buildings' performance and outdoor microclimate conditions. To overcome these limitations, an integrated simulation and parametric design approach was developed. This paper presents the qualitative outcomes of the workshop that investigated the usability and appropriateness of the urban modelling, simulation and design platform prototype which embeds the approach. Workshop participants appraised the integrated features of the prototype and emphasised its potential to promote optimised integrated urban designs that consider the users, the buildings, their surroundings and the microclimate as elements of the same system that sustainably adapt to and mitigate the effects of climate change.

INTRODUCTION

In the current scenario of rapid urbanisation and global warming, cities are experiencing major physical and climatic changes. While, current environmental and energy policies focus on building energy efficiency due to its substantial savings potential, minor attention has been given to the quality of the urban environment and its interrelationship with urban design. This lack of context and climatic consideration leads to buildings being designed as stand-alone systems that rely on energy equipment and processes affecting the health, well-being and productivity of their occupants while increasing building energy consumption. The addition of new buildings to an existing environment can also adversely affect the liveability of the outdoor open spaces, the performance of the surrounding buildings and ultimately, the city-wide conditions by interacting with and redistributing the natural resources available at a place. Wind turbulences and sheltering, solar reflection and overshadowing are some of the complex and dynamic phenomena that can have adverse or beneficial effects depending on the context and climate conditions. Despite they could be manipulated by design interventions, they remain hardly addressed post construction since resulting from the interactions between

the global urban morphology that comprises new and existing buildings and the local climate. There are significant grounds for investigating an integrated design approach that may mitigate risk associated with poor consideration of context in the early design phase of urban buildings.

The concept of integrated design aims to overcome this current lack of interaction between the indoor and the outdoor environments, built forms and open spaces, new and existing buildings, and also collaboration between architects and engineers. However, the implementation of integrated design in practice is currently limited because building performance simulation (BPS) tools do not work well together. While building information modelling (BIM) is providing these tools with the potential to be interoperable in terms of underlying geometrical data, they are mono-criterion or single-phenomenon oriented with limited ability for the performance reported by one tool to become the input for another. BPS tools also typically consider a building to be an isolated object which is away from the urban contextual constraints and microclimate conditions to which building design should respond to create sustainable urban environments (Futcher et al. 2017).

To implement the concept of integrated design, an urban modelling, simulation and design platform is proposed. This platform incorporates accurate physics which is combined with the capabilities of parametric modelling for data exchange, design exploration and performance-driven optimisation. This platform aims to support the implementation of optimised bioclimatic passive strategies (Olgay 2015), particularly during the early stages when design decisions determine how well a project can perform.

To verify whether the developed platform could address existing design tools' limitations and fulfil designers' needs for early design concepts comparison (Donn et al. 2012), a workshop was organised with students and professionals. This paper introduces the underlying multidisciplinary design system which is incorporated in the urban platform tested by the workshop participants. The qualitative feedback and appraisal of the prototype and its decision-support potential from the users' point of view is analysed through a series of two questionnaires.

METHODS

Design tool development: The context and climate-sensitive urban design approach

The proposed urban design approach follows the framework proposed by (Alfaris 2009) and is “built on the strengths inherent in both generative synthesis models and multi-performance analysis and optimisation”. This approach has been selected due to its integrated and holistic nature and its ability to solve complex design problems. The parametric modelling capacities of the software pair Rhinoceros-Grasshopper are used to generate a synthesis model of interrelated urban elements. Topography, buildings, open spaces and natural elements are connected with each other in an algorithmic relation. This process also known as “parametric design” is used to provide a wide range of alternatives at the different scales of urban design (neighbourhood, building block, building mass, envelope elements, pedestrian level...). The complex relationships between form and environmental performance are analysed thanks to several mathematical models with different level of fidelity. All analysis models use the unique parametrised synthesis urban model so that any morphological, topological or data change will influence the whole data. The dynamics of the urban microclimate and its effects on outdoor and indoor conditions is captured by using specific simulation tools (UrbaWind for the CFD airflow, Radiance for solar irradiation, EnergyPlus for indoor thermal conditions) whose outputs are spatially and temporally structured, and exchanged between analysis models in order to evaluate various environmental performance indicators. In addition to the separate evaluation of these phenomena, the simulated data is combined with statistical weather information and appropriate 3D visualisation to confront design options with their dynamic effects on outdoor thermal comfort (UTCI).

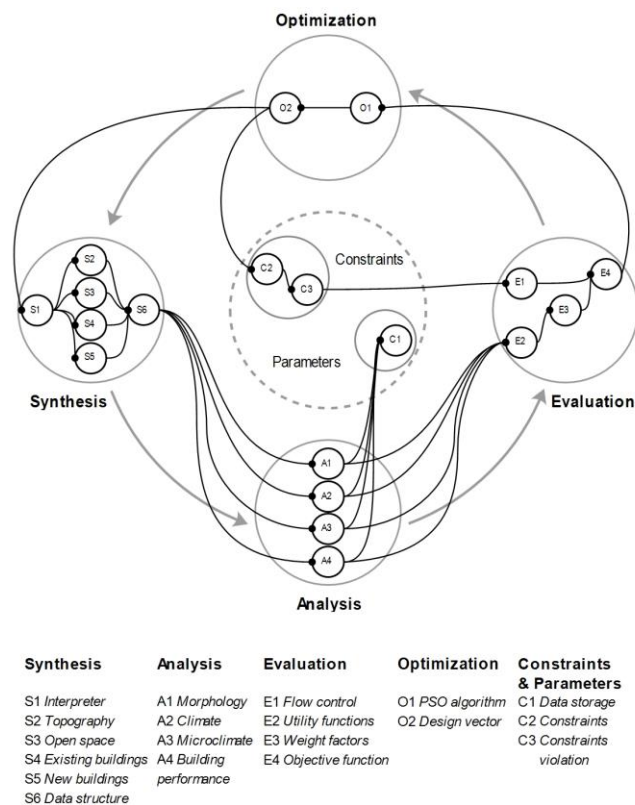


Figure 1. The context and climate-sensitive urban design system. Reproduced and adapted from (Alfaris 2009)

Quantitative metrics are defined in relation to the disciplines and goals involved in bioclimatic design whose essence is to create a favourable microclimate both indoor and outdoor through the application of architectural techniques. Even though some recent studies used parametric modelling to design more responsive and sustainable urban morphology (Eltaweel and Yuehong 2017) they remain mainly focused on the design of the new buildings and don't fully embrace the integrated capabilities of the parametric approach. Here, the novelty of the approach is to consider the urban form as a whole, where the sketch performance of a new building or urban form is optimised and balanced with its microclimatic impact on its existing surroundings. Figure 1 presents the constituent modules of the iterative synthesis, analysis, evaluation and optimisation stages of the urban design system.

Overview of the tested prototype

Following the aforementioned design approach and system, an adaptive graphical user interface (cf. Figure 2) has been developed so different level of complexity and transparency of the underlying mathematical models are accessible according to users' wishes, knowledge and expertise. In addition to the traditional Grasshopper visual programming interface that accompanies the Rhino viewports, a synthetic interface has been developed to control a selected range of synthesis, analysis, evaluation and optimisation activities. This interface allows non-expert users to operate the design system in a user friendly manner. Users with a higher expertise or wishing to understand, tune or customise the prototype and its constituent modules are still able to access the visual programming environment of Grasshopper and are even able to access the core of the analysis modules written with textual code (VB, #C, Python).

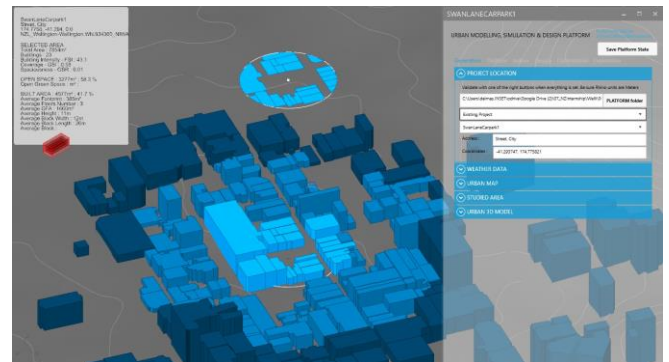


Figure 2. Overview of the graphical user interface of the tested prototype (developed under Rhino-Grasshopper environment)

The prototype control interface, presented on the right side in Figure 2, comprises six main tabs: generation, outdoor evaluation, indoor evaluation, design, optimisation and exploration; all gathering several sub-sections. The first tab deals with the generation of the existing urban environment expected to host a new building development. The generation process uses either typical GIS data (imported by the user) or OSM data (automatically downloaded), to generate successively an urban map (cf. Figure 3) and an urban 3D model of the studied area and its surroundings (cf. Figure 2). The building models are combined with a terrain model generated from satellite topographical data (Shuttle Radar Topography Mission 1) of 20 to 30m resolution. In the case of available detailed terrain elevation data of the studied area, an integrated module allows combining this particular data set with the larger satellite one through a

resampling procedure. The integrated modelling of the topography allows capturing the effects of wind, solar masks and building relative heights in the design system. The radii of the terrain and of the selection of simulated buildings is determined according to the size of the user-defined studied area and the CFD domain size requirements illustrated in Figure 5 by the 3 building crowns (the two outer crowns are only used in the CFD analysis).

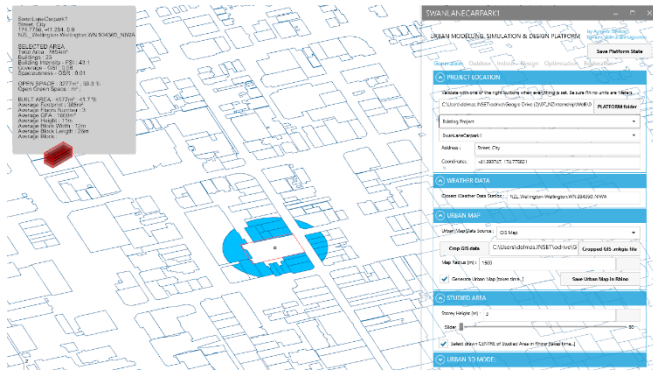


Figure 3. Overview of the GIS urban map of the 50m radius selected area

A 'heads up' display materialised by a textual panel on the left side of the main screen (cf. Figure 4) is used as indicator of the already performed analyses and as continuous descriptor of the evolving morphology (existing and new designed buildings) of the studied area. The power of Grasshopper for manipulating and managing geometric data is used here to calculate several morphology indicators. The developed system identifies the precinct buildings and their heights to derive four density indicators (FSI, OSR, GSI and L). These correlated indicators have demonstrated their usefulness in describing, comparing and exploring various urban forms (Berghauser Pont and Haupt 2009). These indicators reflect respectively the built density, the spaciousness, the compactness and the average number of storeys of a precinct. They serve here to deepen the understanding of the relationships between form, density and environmental performance. Following the same morphological approach, the size of the average building block of the precinct (hypothetically representative of the area) is determined and displayed by the 'heads up' display (cf. Figure 4).

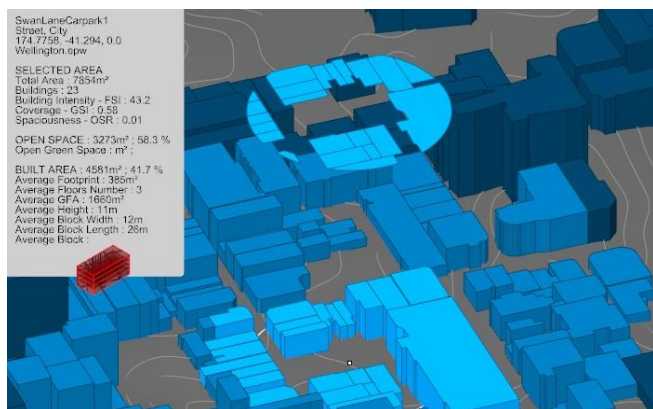


Figure 4. Overview of the 'heads-up' display, morphological indicators and average building block of the selected area

The outdoor and indoor tabs (cf. Figure 6 for an overview) focus on the spatial and temporal multidisciplinary evaluation of the urban environment. From these two control tabs, the

user of the prototype is able to perform different types of analyses related to climate statistics (using the typical weather file closest to the project location, cf. Figure 5, left side), microclimate simulations (solar irradiation, wind airflow, outdoor thermal comfort; respectively computed by the Radiance, UrbaWind and UTCI models) and building performance simulations (indoor daylighting and thermal comfort conditions are simulated by Daysim and EnergyPlus engines). Material thermal and optical properties are kept generic across the urban scene as a first sketch performance exploration. These analyses are first performed on the existing urban environment (buildings and open spaces) before any design activity is achieved through the design tab.

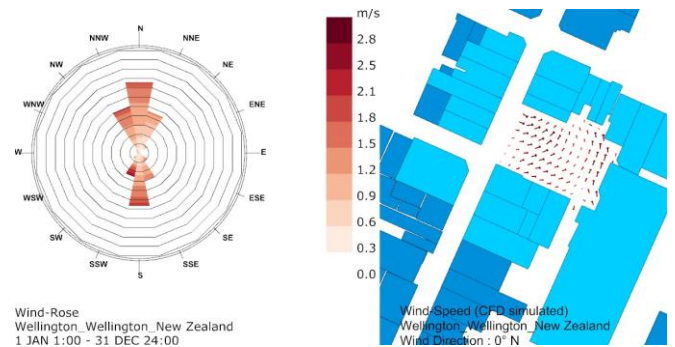


Figure 5. Graphical representation of the airflow climate statistics (wind rose, left side) and microclimate simulation (CFD mean wind speed vectors, right side) outputs at pedestrian level for Wellington city centre, Cuba Street

The design tab provides a set of encoded parametric generative definitions of sketch building blocks which are selectable and tuneable by the user. To not restrict design flexibility, designers are able to integrate their own parametric definitions or 'hard' Rhino models of urban elements such as trees, wind breaks and solar canopies through a specific sub-section of the design tab. Each time requested by the user, the generated designs are integrated into the existing context and the environmental performance simulations recomputed. In the exploration tab, the simulated performance of the initial scenario (i.e. the existing environment) and generated scenarios integrating the new designs can be compared.

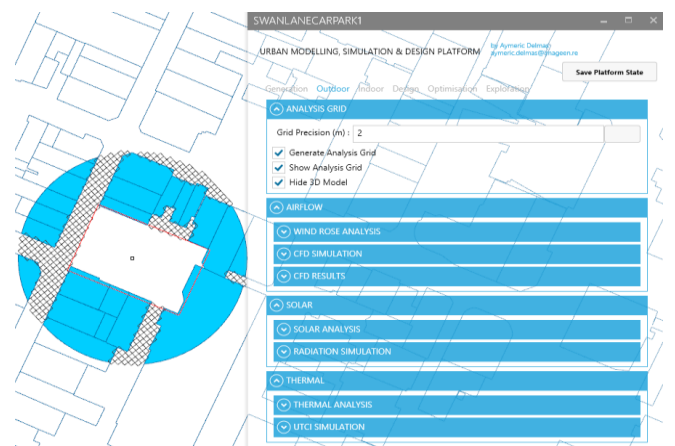


Figure 6. Overview of the analysis grid generated by the outdoor evaluation tab and its constituent sub-sections

An alternative to this manual design exploration of the design space is available under the optimisation tab. In order to take into account multi-criteria optima a utility function approach is selected. The objectives related to each criteria are weighted

and combined into one scalar objective function. Even though, this approach is limited by its prior search definition, it appears appropriate for a wide range of objectives, more especially when a “the more the better” or “the less the better” approach is not applicable (Alfaris 2009). Moreover, by the means of weights and scaled utility functions, a whole discipline can either be prioritised or ignored easily, and desirable and undesirable values for each discipline can be defined according to the designers’ needs. The design space is explored thanks to a particle swarm optimisation (PSO) which rapidly find the best design solution(s) complying with the objective. The PSO technique is selected for its computational speed, intuitiveness and robustness in complex optimisation problems (Rodriguez 2017) such as urban densification and context integration problems.

The urban modelling, simulation and design workshop

To test and demonstrate the usability of the developed approach, an urban modelling, simulation & design workshop was organised. The workshop consisted in the presentation of the platform prototype and in the testing of some of its embedded features within a structured tutorial exercise. The four hour workshop gathered a dozen of participants: post graduate, doctorate students and young practitioners with a common background in either Building Science or Architecture. Experience levels in the design industry ranged from few months to 12 years with an average of 2 years of experience. To obtain qualitative and quantitative data, a series of two surveys, one pre workshop and one post workshop, was given to the participants.

The first questionnaire focused on (1) the experience of the participants and (2) the tools, methods and barriers encountered in their digital design practice. In order to not influence participants’ responses, this first survey was performed before any presentation or testing. The gathered data is used to contextualise the results of the post workshop survey. This second questionnaire allowed assessing the general potential, usability and current limitations of the prototype as an urban design decision-support tool from the users’ feedback and appraisal.

Table 1. Design tool criteria (categories) and features (subcategories) used for coding qualitative responses

UIM	IIDKB	AADCC	IBM	IBDP	EIDP
•Graphical representation of output results •Adaptive GUIs •Interface as educational •Transparency of assumptions & calculations	•Informing design decision making •Templates & databases •Parametric capabilities •Optimisation capabilities	•Accurate & realistic results •Accuracy of model	•3D model & data exchange •Exporting to BIM	•Fluidity of modelling within different phases •Multidisciplinary assessment & communication •Context considerations	•Designer perception on workload •Cost •Prioritisation •Expertise

In order to relate this work with previous studies on the same topic, the six-category coding scheme used by (Braasch 2016) was adopted to summarise participants’ responses to the questionnaires. The six following categories relate to the tool development criteria most reiterated by the architecture and simulation community (Attia et al. 2009): usability and information management (UIM) of interface, integration of intelligent design knowledge-base (IIDKB), interoperability of building modelling (IBM), accuracy of the tool and its ability to simulate complex and detailed building components (AASDC), integrated building design process (IBDP) and the external influences on design process (EIDP). Table 1

presents the subcategories resulting from the coding of the qualitative responses of the participants to the open-ended questions asked during the pre and post workshop surveys.

RESULTS

Pre workshop questionnaire: participants’ design experience and practice

When asked about the design scales and phases they usually work at, respondents mentioned they initiate their work during the concept design (CD, 58% of the panel) or even later at the detailed design phase (DD, 67%) of a building project. Very few start working on an urban project at the political decision phase (PD, 8%) or the urban design phase (UD, 17%). Even though, the latter are the phases of planning and design where critical choices can be made for integrating context and (micro)climate information in urban environments like solar energy (Kanters and Wall 2016), this is usually postponed to latter design phases and performed at the building scale as illustrated in Figure 7.

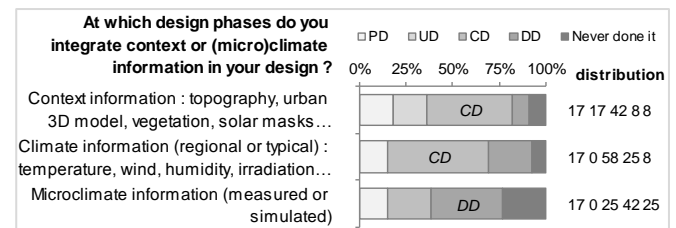


Figure 7. Results from the pre workshop questionnaire regarding design process greatest barriers to context and climate sensitive urban building design

This lack of environmental sensitivity is, according to the respondents, due to different barriers related to the digital design process. When asked about the five most critical ones, designers assert external influences (cf. Figure 8) such as design perception on workload (33%), prioritization (33%), expertise (25%) or cost (17%) limit their consideration of the context and the climate while designing. The defined integrated nature of the current design tools and process is also highlighted by the workshop participants with a dearth of context consideration (33%) and limited accuracy of the models (25%) used.

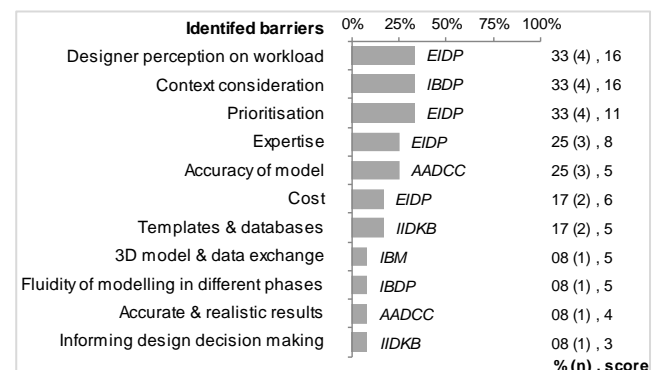


Figure 8. Results from the pre workshop questionnaire regarding design process greatest barriers to context and climate sensitive urban building design

Regarding their familiarity with performance-driven design activities, participants responded they use parametric design exploration as a driven force mostly at the conceptual design stage (58%) when few elements about the project is known and so when most design freedom and impact on the final

performance is possible. Participants mentioned also they usually support this explorative activity with the sensitivity analysis of performative goals to individual design parameters (50%), still during the definition of the design concepts. This is again in accordance with the development choices aforementioned. Finally, results in Figure 9 indicate that surveyed designers are fewer to integrate optimisation activities in their design processes and even a quarter of them never practiced before.

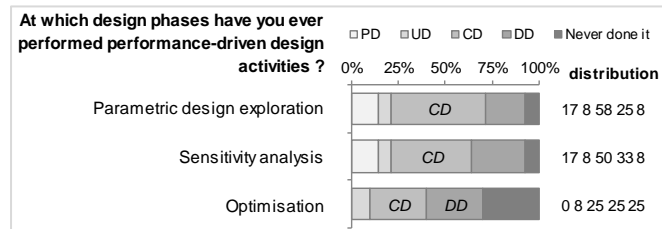


Figure 9. Results from the pre workshop questionnaire regarding participant's familiarity with performance-driven related activities

Post workshop questionnaire: users' feedback and appraisal of the developed prototype and supported approach

The responses to the post workshop questionnaire are presented in Figure 10. The first three bar charts illustrate the distribution of answers in terms of agreement (on a 5-point scale) with the proposed statements on the left of the graphs. Regarding the design approach proposed and materialised by the prototype, users agreed and were satisfied generally with most of the embedded features as illustrated by the first three graphs. The majority of the participants' responses was positive with very few under the neutral rank on the five-point scale (cf. the distributions of responses on the right hand of the first three graphs in Figure 10). Only the design influence of using the prototype was averagely rated ("Good", 50%, chart 3) which can be explained by some technical issues that occurred during the workshop.

Finally, participants were asked in two open-ended questions to index the most useful and the most needed features of the prototype. Their coded responses are summarised in the last two charts in Figure 10. The multidisciplinary assessment capabilities of the prototype was plebiscited (100%, Figure 10, chart 4) by the participants. The consideration of the existing urban context in addition to the ease of use and adaptivity of the graphical user interface were also highly appreciated (67% for both features, Figure 10 chart 4). Even though no particular missing feature was highlighted by the categorisation of the questionnaire responses, multiple suggestions were given to overcome the limitations of the tested prototype. The integration of clear instructions and tips in the interface ("Interface as educational", 25%, Figure 10, chart 5) and of descriptive comments of the selected assumptions and performed calculations ("Transparency of assumptions", 25%, Figure 10, chart 5), would enhance its usability and information management, and therefore limit the black-box nature of the platform which is one of the predominant weaknesses of current BPS tools. Participants mentioned other interesting suggestions of improvement related to the integration of more detailed modelling features such as "stochastic human behaviour" or "detailed parametric shadings".

DISCUSSION

Main findings

Workshop participants and prototype testers validated in general most of the development choices integrated in the urban modelling, simulation and design platform.

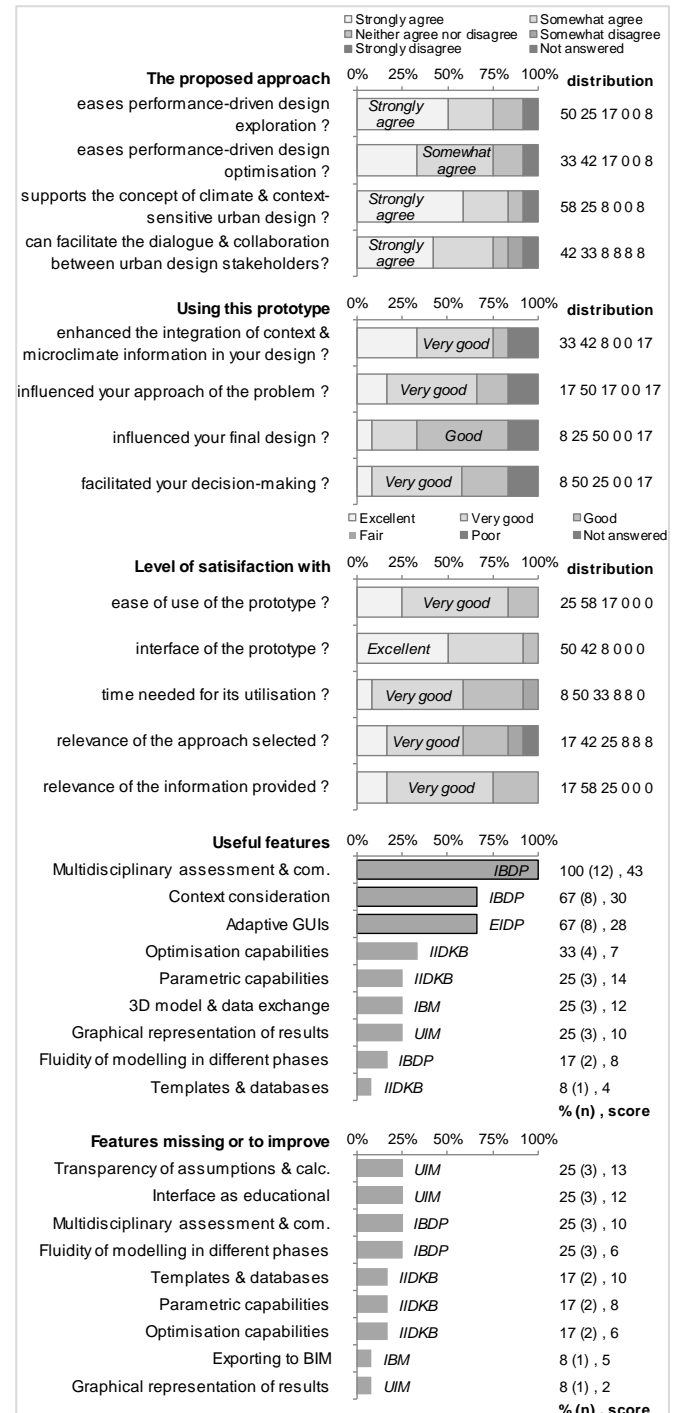


Figure 10. Results from the post workshop questionnaire regarding the prototype users' appraisal

They particularly highlighted the usefulness of the automated modelling of the existing urban environment and its integrated multidisciplinary assessment for designing more context and climate sensitive urban forms. The adaptivity of the graphical user interface of the prototype was also greatly appreciated by the users who asserted the importance of this feature to meet different levels of modelling expertise and

priorities. This is accordance with previous designers' appraisal of the feasibility of building performance sketching (Braasch 2016), (Nault et al. 2016) which is facilitated by the customisation capacities and open nature of the visual programming language Grasshopper. Moreover, the selection and integration of accurate, widely adopted, validated and identified as powerful urban-level simulation tools (Allegrini et al. 2015) such as Radiance or EnergyPlus, make this approach particularly adapted to the integrated design process. Indeed the sketch models created when little information is known about the project can be refined iteratively since the same tools are used throughout the design phases in a bottom-up construction of the design system. At last, the influence of the approach on design is enhanced compared to existing performance simulation tools thanks to the optimisation capabilities integrated into the platform which allows bringing performance-driven knowledge and improve a design's performance from early phases.

Limitations

In addition to the missing features identified by the users, feedback speed is one of the acknowledged limitations of the developed prototype. Although, it is dependent on numerous parameters such as computer power, scale of the user-defined precinct, type and internal assumptions of the analysis performed, this limitation is balanced by the flexibility of the approach. Indeed, users of the prototype are able to tune the spatial and temporal scales of the simulations during the manual exploration of the design space. The design flexibility and feedback time reduction is also supported by the multi-criteria single objective optimisation approach where a whole discipline can either be prioritised or ignored easily. The limited sample of prototype testers is also a limitation of this study. A new workshop, with an improved prototype that takes suggested improvements into account and with a larger number of participants with a higher level of experience in the industry, would support the qualitative findings presented in this paper.

Sustainable urban design implications

The young professionals and students who attended this workshop demonstrated the high educational potential of the approach. The flexibility and modularity of the visual programming and the parametric modelling allow users to customise and adapt the developed tool to particular needs. By these means, students, future practitioners, can be initiated to context and climate sensitive urban design, to the integration of performance and environmental criteria in the design process and ultimately to multi-criteria and multi-scale optimisation problems (Delmas et al. 2016), crucial features for the reduction of our cities' ecological impact and future. Finally, the supported concept of context and climate sensitive optimised urban form embedded in the proposed approach could be further expanded to not only limit the impact of new buildings integration but also to have a mitigative effect on the environmental performance of the urban environment by using new built forms as positive modifiers of the microclimatic conditions.

CONCLUSIONS

An integrated simulation and parametric design approach was developed and implemented as a prototype to support context and climate sensitive urban design. An urban modelling, simulation & design workshop gathered design students and professionals in order to appraise the usability and appropriateness of the prototype especially during the

early conceptual design phase activities. The workshop participants provided qualitative feedback regarding the integrated features and current limitations of this novel design system. The ease of use, the design flexibility and the adaptivity of the graphical user interface, as well as the context consideration and the multidisciplinary simulation-based assessment of the urban environment were emphasised by the prototype testers. These features have the potential to promote optimised integrated urban designs that consider the users, the buildings, their surroundings and the microclimate as elements of the same system that sustainably adapt to and mitigate the effects of climate change.

ACKNOWLEDGEMENT

The authors thank VUW staff and the participants who attended the Urban Modelling, Simulation & Design Workshop, organised at the School of Architecture of Victoria University of Wellington. This work is part of a doctoral study funded by the design office Imageen with the support of the French national association for research and technology (ANRT).

REFERENCES

- Alfaris, A.A.F., 2009. *Emergence through conflict: the Multi-Disciplinary Design System (MDDS)*.
- Allegrini, J. et al., 2015. A review of modelling approaches and tools for the simulation of district-scale energy systems. *Renewable and Sustainable Energy Reviews*, 52, pp.1391–1404.
- Attia, S. et al., 2009. Architect Friendly": a comparison of ten different building performance simulation tools. In *Eleventh International IBPSA conference*.
- Berghauser Pont, M.Y. and Haupt, P.A., 2009. *Space, density and urban form*.
- Braasch, E., 2016. *The feasibility of Building Performance Sketching within the building design process*. Victoria University of Wellington.
- Delmas, A. et al., 2016. Solar potential in extreme climate conditions: comparative analysis of two district case studies in Norway and Reunion Island. In *Symposium on Simulation for Architecture and Urban Design*.
- Donn, M., Selkowitz, S. and Bordass, B., 2012. The building performance sketch. *Building Research & Information*, 40(2), pp.186–208.
- Eltaweel, A. and Yuehong, S., 2017. Parametric design and daylighting: A literature review. *Renewable and Sustainable Energy Reviews*, 73, pp.1086–1103.
- Fletcher, J. et al., 2017. Creating sustainable cities one building at a time: Towards an integrated urban design framework. *Cities*, 66, pp.63–71.
- Kanters, J. and Wall, M., 2016. A planning process map for solar buildings in urban environments. *Renewable and Sustainable Energy Reviews*, 57, pp.173–185.
- Nault, É. et al., 2016. Urban planning and solar potential: Assessing users' interaction with a novel decision-support workflow for early-stage design. In *Proceedings of Sustainable Built Environment (SBE) Conference*.
- Olgay, V., 2015. *Design with climate: bioclimatic approach to architectural regionalism*, Princeton University Press.

Cichocka, J., 2017. SILVEREYE-The Implementation of Particle Swarm Optimization Algorithm in a Design Optimization Tool. In *Computer-Aided Architectural*

Design: Future Trajectories: 17th International Conference, CAAD Futures 2017, Istanbul, Turkey, July 10-14, 2017, Proceedings. p. 151.