The Virtual and the Physical
Between the representation of space and the making of space

A. Benjamin Spaeth
Wassim Jabi
eCAADe RIS 2017

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Welsh School of Architecture, Cardiff University, Wales, United Kingdom

1st Edition, April 2017

The Virtual and the Physical. Between the representation of space and the making of space. Proceedings of the 5th eCAADe Regional International Symposium, Welsh School of Architecture, Cardiff University, 26-28 April 2017. Volume 1 edited by A. Benjamin Spaeth and Wassim Jabi, Welsh School of Architecture, Cardiff University, Wales, United Kingdom.

ISBN 978-1-899895-26-7

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Publisher: eCAADe Education and Research in Computer Aided Architectural Design in Europe, Brussels and the Welsh School of Architecture, Cardiff University, Wales, United Kingdom.

Cover design: A. Benjamin Spaeth, Alexander Opoku

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Edited by
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The Virtual and the Physical

*Between the representation of space and the making of space*

The realm of computation in architecture extends from the virtual representation of space through to its physical making. Beyond the visualisation of space we are concerned with the different models of space to explore and uncover its relevant properties. At the symposium we explored the dimensions of space beyond its physical existence and tried to understand the implications of computation in architecture on social, political and environmental discourse.

At the other end of the spectrum computation in architecture seeks to optimise, automate and integrate effective methods and concepts into architectural production. Through biomimicry/biophilia and material computation, we explore alternative approaches to spatial construction. We are interested in the gravitational field between the aforementioned extreme ends of computation in architecture. At the symposium we intend to uncover how computation in design and fabrication influences our understanding of space and, reciprocally, how the computational representation of space impacts the production of architecture. We aim to reach to the extremes of the spectrum of architectural space to critically speculate about its creation in theory and practice.

We called for academic papers, practical work or design propositions that engage with the transition from the virtual to the physical, or vice versa and that explore the realm between the representation of space and the making of space. We are interested in how we represent architectural space and its manifold diversity of social interactions, economic determination, environmental impacts, functional requirements and spatial quality to make it available and impactful on computational design processes.

Some questions include: How does architectural space manifest itself in built shape and solid form? How do we represent non-geometrical parameters to find their role in the design process? How do we account for spatial quality to be sustained during computational design procedures? Where do we integrate potential social interaction and functional interconnection in the various design systems? What are the driving forces of architectural design computing?
Apparently these questions exist in academia but they are increasingly infiltrating architectural practice. The question of what and how and who is influencing and controlling the design process is increasingly pressurising the practicing architect. Is the academic promise of computationally-driven design really viable in practice? Is robotic fabrication an alternative way for mass customising building elements in a cost-effective way? How is virtual reality supportive in the daily design routine of architectural practices? What are some of the viable procedures to transform the virtual representation of space into the physical space of a building? What material properties impact the fabrication process and become manifest in the design system?

Evidently the advances in integrating computation into architectural design and production has a vast influence on how we educate future architects at our universities. We are interested in how education has changed. We want to discuss how methods of learning and teaching have changed, what content has been added to curricula and what impact this might have had – and will have - on the understanding of pedagogy, architecture and computation.

A. Benjamin Spaeth
Wassim Jabi
Acknowledgments

We, the organisers of the 5th eCAADe Regional International Symposium (RIS2017), are grateful to the many helping hands who made it possible for us to bring people from different parts of the world together at the Welsh School of Architecture (WSA) in Cardiff to share and discuss their latest research in computational architecture and design.

We want to thank Joachim Kieferle, President of the eCAADe, for trusting the organisation of the RIS2017 to us at the WSA. The intellectual and practical support by Jose Manuel Pinto Duarte, Bob Martens, Henri Achten and Nele de Meyere was greatly appreciated.

We are extremely grateful for the outstanding web-based services provided by Martin Winchester, Gabriel Wurzer and Wolfgang E. Lorenz in handling the paper submission, including their peer-review and editing the proceedings.

At the Welsh School of Architecture we received generous support from Chris Tweed, Head of School, whose trust in our acquisition and running of this symposium at Cardiff has, we hope, borne out its success.

Among the many people at WSA who supported the RIS2017, we want to mention Alicia Nahmad Vazquez for her indefatigable engagement: initialising, organising and coordinating the “Frictional Assemblies” workshop.

Last but not least we want to thank the eCAADe for providing basic funding for the symposium. Without the financial support this symposium would not have been possible.
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The eleven papers presented in this volume have gone through a double blind review by a scientific review committee consisting of distinguished academics in the field of computation in architecture as well as practitioners who apply computational methods in their architectural work.

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Investigating Spatial Configurations of Skycourts as Buffer Zones in High-Rise Office Buildings

Coupling building energy simulation (BES) and computational fluid dynamic (CFD)

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Skycourts are attracting widespread interest in the contemporary construction of high-rise commercial buildings. Due to their remarkable function as public realms and transitional nodes, those spaces could introduce alternatives to the vernacular courtyards/atriums in high-rise buildings. This paper outlines the methodology that was adopted to examine the performance of basic spatial configurations of skycourt in high-rise office buildings in a temperate climate. Significantly, these areas accomplished as buffer zones that are non-ventilated and unheated while accommodating combined ventilation strategy. The study is processed via coupled simulation between a building energy simulation (BES) and a computational fluid dynamic (CFD). The developed coupling approach aims to improve the prediction for skycourt performance that is essential for the assessment of thermal comfort conditions and energy consumption. Results to nominate the optimum spatial configuration of skycourt along the vertical section of the high-rise office buildings are discussed briefly. However, the focus is on the methodology.

Keywords: Skycourt, Spatial Configuration, Coupling Simulation, Thermal Comfort, Energy Efficiency

INTRODUCTION
The skycourt, by its various configurations, is recognised as communal areas in high-rise commercial buildings, established from the concept of the courtyards in low-rise buildings. They function as public social void spaces which can provide leisure; wellbeing for workers, obvious connections and social interaction as hubs. They could perform such as areas for circulation and transition. Moreover, they could perform as buffer zones between the indoor and the outdoor thus could mediate the climate conditions, provide thermal and acoustic protection to the interior and reduce heat loss. Furthermore, skycourt can offer a contemporary alternative to the vernacular courtyard or atrium in high-rise buildings due to its potential to allow natural light and ventilation to
enter deeper into the interior of the high-rise building and avoid unwanted solar gain (Goncalves and Umakoshi, 2010; Pomeroy, 2008, 2007; Yeang, 1999).

Therefore, these areas could play a promising role in conserving energy and improving the thermal comfort for buildings (Alnusairat and Elsharkawy, 2015; Pomeroy, 2014). The perspectives of obtaining significant reductions in energy consumption besides enhancing the thermal comfort of users in these areas are considered in this study. The paper is part of research seeks to investigate the energy saving potentials associated with the modification of the skycourt design. This objective could be achieved by demonstrating skycourt as an integrated buffer element in high-rise office buildings and exploring its consequence on reducing demand for heating and cooling, besides potential advantages on occupants’ thermal comfort at the skycourt, in temperate climates such as London.

### COUPLING STRATEGY: BUILDING ENERGY SIMULATION (BES) AND COMPUTATIONAL FLUID DYNAMIC (CFD)

A large and growing body of literature has argued that simulation plays an important role as an intermediate point of knowledge for developing design solutions in construction. It is a useful technique for developing and testing theory, in addition, it could be used as a design tool for generating design alternatives, predicting performance and defining the optimum solution that improves performance. This technique could be conducted for analysing the effect of space(s), the system(s) or device(s) at several scales to inform more details (Groat and Wang, 2013).

However, methods for modelling the ambient conditions concerned for investigating thermal comfort, air containment and energy efficiency could be divided into two groups: physical models and numerical models. These differ in the base of modelling techniques and level of details for the input data. The physical (reduced scale) models could represent or reproduce the characteristics of the full-scale physical context or system, such as materials and products that are readily manipulated by exper-
The spatial configurations of skycourt (the white shaded zone) floor plans considered in the study: (A) hollowed-out, (B) corner, and (C) sided prototypes.
solve the equations by dividing the spatial continuum into cells among grid, which requires iterations to achieve a converged solution (Zhai et al., 2002). In contrast, the Building Energy Simulation (BES) stands on the principles of energy (heat) balance equations that considers the internal heat transfer between the space air and surface. These include energy balance equations for a space air, for a surface (e.g. wall and window) and for the radiative heat flux (Zhai et al. 2002). Therefore, BES could provide thermal, energy analysis for the whole building and the HVAC systems. The output of this simulation includes mean (average) air temperature, heating, cooling, ventilation, solar gain, fabric and incidental loads. BES could be obtained on an hourly basis for the whole year. Unfortunately, this type of simulation assumes air as well-mixed. Therefore, it is unable to provide detailed predictions of the spaces’ indoor air properties such as the distributions of air velocity and temperature, the relative humidity and the contaminant concentrations (Zhai et al. 2002; Zhai and Yan 2003). Therefore, it is argued that integrating BES and CFD together can produce complementary information for the energy consumption and the indoor thermal comfort for buildings. Furthermore, it is agreed that the coupled simulation can predict more accurate, detailed and quick results compared to the separate simulation (Barbason and Reiter, 2014; John and Yan, 2005; Wang and Wong, 2008; Zhai et al., 2002; Zhai and Yan, 2003). The coupling approach stands on providing the interior surface temperatures and the heat extraction rate that are obtained from BES to the CFD model so the airflow simulation could calculate specific air thermal conditions (Zhai et al. 2002). Therefore, the CFD model can receive more exact and real-time internal thermal conditions thus can predict the dynamic indoor thermal conditions. This significance is essential for the assessment of indoor air quality and thermal comfort. Moreover, the BES can obtain more accurate convection heat transfer coefficient from the boundary envelope. This process produces a more precise calculation of energy demand and full thermal behaviours of the building enclosure (John and Yan 2005). In addition, using this mechanism of integration can eliminate few assumptions that handled via each separate application, reduce the computation time of CFD (Wang and Wong, 2009; Zhai and Yan, 2003).

There are two major approaches for coupling thermal and CFD simulation to reduce computing time-cost: the static coupling and the dynamic coupling. However, Zhai et al. (2002) distinguished a third key strategy for coupling simulation. That is the bin coupling. The static coupling process includes one-step or two-step data exchange between BES and CFD programs. The process can be performed manually with a few coupling iterations and does not require hard modifications of individual ES and CFD programs. While, the dynamic coupling process requires continuous coupling between the BES and the CFD at each time step. This method may occur in one-time step, quasi-dynamic or full-dynamic. The one-time-step focuses on the coupling at one specific time step of interest. At that point step, the iteration between ES and CFD is carried out to reach a converged solution. However, coupling might happen without iteration at each time step in a period such as in the quasi-dynamic. That is the CFD simulation obtains the boundary conditions from the previous BES calculation at the specific time step, then returns the thermal information of indoor air to BES of the next time step. The full dynamic coupling involves iteration between BES and CFD to reach a converged solution at each coupling time step before moving on to the next step. In the bin coupling process, the BES receives info that is pre-calculated by the CFD and saved it in the bins to be used for subsequent energy computation (Zhai et al. 2002).

Generally, the approaches of exchanging data between the BES and the CFD modules may be classified depending on the type of data transfer into three methods. In the first method, the indoor surface temperatures transfer from BES to CFD, then convective heat coefficient and indoor air temperature from CFD to BES. The second approach considers transferring indoor surface temperature from BES to CFD
and then convective heat flux from CFD to BES. The third method includes transferring interior convective heat flux from BES to CFD and then returns convective heat coefficient and indoor air temperature gradients from CFD to BES. Method one is considered the most appropriate one due to its stability. However, method two is the most expensive one since it requires explicit in BES and implicit in CFD. Whereas, method three is not recommended since it is unable to control air temperature (John and Yan, 2005; Zhai and Yan, 2003).

The next section describes the coupling simulation approach that is adopted in the study.

INTEGRATING HTB2 AND WIN AIR FOR THE SKY COURT ANALYSIS

HTB2 and WinAir are used in this study. The HTB2 software version 10 is used to inform the thermal performance and energy efficiency while WinAir Version 4 is adopted as a CFD simulation to inform the ventilation performance inside the sky court. The input data required for the HTB2 comprises information of both the regional climate data and the building, including info regarding the building size, construction materials, small power, building services (heating, lighting, ventilation and occupancy) during the occupation and avocation periods and the diary of application. The output data includes thermal conditions represented by air temperature, air humidity, mean radiant temperature, element surface temperature, and mean surface temperature. Furthermore, energy performance embodied by space gains and losses from heating, cooling, incidental, solar, ventilation and fabric loads. The output information could be in the form of power (W) or energy (kWh). This information could be based on the hourly, daily, monthly or yearly database. On the other hand, the WinAir software requires knowledge of the building size, inflow and outflow rate in case of fixed flow rates (mechanical ventilation), pressure boundaries in case of varying flow rates (openings -natural ventilation), internal heat gain and heat loss and pollutant conditions in the event of source of contaminants. See figure 3. The climatic data considers specific time at the specific date. The study investigates the performance of sky court in summer, winter and transitional seasons emplacing the hottest hour, the coldest hour and mid-temperature hour. The output data comprises graduating information of air temperature, air velocity and air concentration showing the airflow pattern.

The paper aims to predict the indoor air temperature, and the air velocity at the occupancy level of the sky court under the assumption that these zones are buffer areas do not consume energy for heating neither cooling. However, constant air supply that exhausts from the adjacent offices’ zones is assumed to modify the internal environment of the sky court. Similar conditions are conducted for the three spatial configurations to perform the fair comparison. External coupling is adopted in this study to ensure accurate prediction of the indoor environment for the sky court, and to eliminate time cost. Therefore, two models should be built separately in the HTB2 and the WinAir. A schematic model was developed in the energy simulation to predict the thermal conditions inside the sky court space and the energy consumption for heating, cooling and ventilation, considering that the sky court space consists of three zones; lower, middle and upper zone. Furthermore, a grid model was built in the WinAir to investigate in details the airflow phenomena - air temperature and velocity. Data exchange for boundary conditions is needed to bridge the two programs. The static coupling strategy is chosen to couple the two simulations. The thermal conditions for the CFD (WinAir) simulations are obtained from previously calculated values from the energy modelling software HTB2. These include the surfaces’ heat transfer, the inlet -air supply, the outlet -air exhaust and the internal heat gains involved inside the sky court. Then, the resulted temperature from the CFD simulation was compared with the average sky court temperature from the BES to find the predicted temperature difference. The temperature difference was small (approximately 1° C). That little difference is usually accepted for venti-
lation cases to continue the simulation for the next time step (Wang and Wong 2008). Therefore, one-step data exchange was adopted in the study.

RESULTS AND COMPARATIVE ANALYSIS

Results from the energy simulation for the annual energy demand for heating and cooling the buildings are represented in Figure 4. The difference of energy demand for heating and cooling in the building between the selected prototypes is small. Detailed monthly heating, cooling, solar, fabric, ventilation and power loads for the skyscourts are shown in Figure 5.

Figure 6 provides an overview of the thermal conditions including air temperature, mean radiant temperature and the external air temperature, further, it presents the heating, cooling, ventilation, incidental, solar and fabric loads at the lower zone of the skyscourt in the hottest week in summer for the three prototypes (A), (B) and (C).
Figure 5
Results from BES of monthly heating, cooling, solar, fabric, ventilation and power loads for skycourts

Figure 7 illustrates the specific gradient thermal conditions -air temperature and air velocity obtained from the CFD simulation for one case simulation at 14.00, 28 June.

The results from the BES and CFD simulation are highlighted in Table 1. It is apparent from this table that CFD simulation can provide accurate information at the occupancy level of the skycourt related to the comparison criteria, while the BES provides an average temperature for the whole skycourt space. The table shows that there is a small temperature difference (nearly 1 °C) between the two models. This provides strong evidence of the efficiency of integrating both the HTB2 and the WinAir programmes. Overall, the results indicate that skycourt prototype A is the best among the three prototypes in terms of thermal comfort - air temperature and air velocity and energy consumption reduction for the building.

CONCLUSIONS

The paper has described a method to explore the thermal performance and the energy consumption of several spatial configurations of skycourt in high-rise office buildings in a temperate climate. The coupling simulation system of integrating BES and CFD is recommended for studies that examine the thermal performance of spaces in details at specific zones within the whole space. Significantly, studies that use simulation as a design tool. It can be seen from the simulation results that the method shows efficiency to study the thermal conditions at the skycourt space. Therefore, this approach could be applied to investigate spaces that are humongous and tall such as skycourt, atriums, courtyards and plazas. However, to further improve the accuracy of the results, segmentation of the skycourt space in the BES model into more than one space to obtain more specific results to feed to the CFD model is recommended.

It is anticipated that the coupling of HTB2 and WinAir programmes produce minimum temperature difference (nearly 1 °C). This result acknowledges the corresponding and compatibility between the two programmes. Therefore, the technique described in this paper to couple HTB2 and WinAir programmes could be applied to predicting the indoor environment of other spaces.

The comparison between the three spatial configurations of skycourt (A, B and C) regarding thermal comfort - air temperature and air velocity- and energy loads shows that prototype A is the recommended configuration.
Figure 6
Results from the BES of thermal conditions and loads in skycourt -A, B and C models at summer
Figure 7
Results from CFD of the thermal conditions - air temperature gradient (°C) and air velocity (m/s) in skycourt - A, B and C models at 14.00, 28 June, summer, External air temperature is 28.3° C, RH is 42%. Location of cross sections is shown in figure 2.
Table 1

Summary of coupling results from BES and CFD

<table>
<thead>
<tr>
<th>Skycourt</th>
<th>Simulation</th>
<th>Air temperature (*C)</th>
<th>Airspeed (m/s)</th>
<th>Air temperature (*C) at occupancy level</th>
<th>Airspeed (m/s) at occupancy level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation at hot day at summer/ 28 June –14.00, external air temperature: 28.3* C, RH: 42%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>BES</td>
<td>27.8</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>CFD</td>
<td>23.0-30.2</td>
<td>0.114</td>
<td>23.0-26.0</td>
<td>0.20</td>
</tr>
<tr>
<td>B</td>
<td>BES</td>
<td>28.4</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>CFD</td>
<td>23.0-31.5</td>
<td>0.114</td>
<td>23.0-27.0</td>
<td>0.22</td>
</tr>
<tr>
<td>C</td>
<td>BES</td>
<td>31.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>CFD</td>
<td>23.0-35.0</td>
<td>0.066</td>
<td>23.0-27.7</td>
<td>0.15</td>
</tr>
<tr>
<td>Simulation at cold day at winter/ 7 December –09.00am, external air temperature: -5.1* C, RH: 95%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>BES</td>
<td>14.7</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>CFD</td>
<td>13.4-19.0</td>
<td>0.323</td>
<td>14.0-19.0</td>
<td>0.34</td>
</tr>
<tr>
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<td>BES</td>
<td>14.1</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>CFD</td>
<td>11.6-18.9</td>
<td>0.336</td>
<td>12.5-19.0</td>
<td>0.35</td>
</tr>
<tr>
<td>C</td>
<td>BES</td>
<td>12.8</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>CFD</td>
<td>11.1-18.8</td>
<td>0.436</td>
<td>11.0-18.8</td>
<td>0.51</td>
</tr>
<tr>
<td>Simulation at typical day at spring/ 19 April –09.00am, external air temperature: 13.2* C, RH: 91%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>BES</td>
<td>20.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>CFD</td>
<td>20.0-21.6</td>
<td>0.198</td>
<td>20.0-20.7</td>
<td>0.17</td>
</tr>
<tr>
<td>B</td>
<td>BES</td>
<td>20.7</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>CFD</td>
<td>20.0-22.2</td>
<td>0.191</td>
<td>20.0-20.9</td>
<td>0.18</td>
</tr>
<tr>
<td>C</td>
<td>BES</td>
<td>21.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>CFD</td>
<td>20.0-22.5</td>
<td>0.094</td>
<td>20.0-21.0</td>
<td>0.13</td>
</tr>
</tbody>
</table>

ACKNOWLEDGEMENT
The authors would like to thank Al-Ahliyya Amman University, Jordan for funding this research

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