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Effective computational support for knowledge-based design and operation of bio-climatically sensitive buildings

Abstract

The present contribution sheds light on an ongoing research effort toward provision of effective computational support for knowledge-based design and operation of bio-climatically sensitive buildings. Thereby, two sources of knowledge are brought together: i) historical traditions of climatically adapted vernacular architecture, and ii) methods and tools for predictive modeling of the hygro-thermal behavior of built structures. Although computational building performance tools have been available for a long time, their application in the building delivery process cannot be considered to be pervasive. This circumstance is rather unfortunate, as such tools have the potential to effectively support the navigation of the design-performance space. To support climatically sensitive building design and operation, we describe in this paper a knowledge-based, performance-guided design assessment strategy and a corresponding too, tailored toward applications in the context of Indonesia, a country that faces challenges such as natural hazards and rapid urban growth but also possesses vast resources and rich cultural diversity. This research effort will be embedded in the proposed Tra2in research collaboration. Thereby, the proposed interdisciplinary character of the participants is expected to provide valuable synergies, thus enriching both the knowledge base and usability consideration concerning the proposed methodology and associated tools.

Keywords: Design support environments, building performance simulation, vernacular architecture, bio-climatic architecture, Indonesia

1. INTRODUCTION

This contribution concerns one of the trusts of an envisioned interdisciplinary research center dedicated to the study and promotion of climatically responsive architecture in Indonesia. This specific trust aims at a synthesis of two sources of knowledge toward provision of computational support for climatically adapted building design and operation support:

- The first source pertains to the historical traditions of climatically adapted vernacular architecture (Deralla and Mahdavi 2013, 2010; Mahdavi 2007, 1996; Orehounig and Mahdavi 2011, 2010). The embedded knowledge of these traditions is believed to be rooted in evolutionary processes, whereby the behavior of built structures were observed and experienced over centuries in the context of regional climatic circumstances. Intelligent features of regional traditions in architecture may have thus emerged from the long-term iterative process of selection and embellishment of building design features that were found to be conducive to building integrity and indoor environment.

- The second source relates to the application of methods and tools in physics, mathematics, and computer science toward scientific understanding and predictive modeling of the dynamic behavior of built structures given the external – micro-climatically specific – boundary conditions and internal – user-dependent – processes (Mahdavi 2011). Building physics and building informatics thus facilitate the development of methods and tools to support knowledge-based building design and operation.

The recognition of the potential of computational building performance modeling and assessment tools has led to the development of a large number of such tools. Nevertheless, their deployment in (and thus their impact on) the building delivery process cannot be considered to be pervasive. Specifically, with regard to the bio-climatic architectural design support, additional efforts are needed to achieve higher levels of efficient tool development and process-integrated tool deployment. Improvements in this area could address, amongst other factors, the following two issues:

- Advanced numeric building performance simulation tools typically require an extensive set of input data concerning building fabric, building systems, internal processes, and external boundary conditions. The frequency and consistency of tool deployment can be presumably improved, if models can be made to work with input data of smaller magnitude and lower resolution.

- Performance simulation tools can generate large quantities of data, but do not necessarily offer sufficient support for organizing, visualizing, and interpreting such data. In other words, conventional building simulation applications do not sufficiently and effectively support the navigation through the so-called "design-performance space".

2. THE DIMENSIONS OF THE DESIGN-PERFORMANCE SPACE

Comparative performance-based evaluation of building design alternatives can benefit from specific forms of building design and performance representation. One such formalism involves the representation of designs and their performance in a multi-dimensional design-performance space (Mahdavi and Gurtekin 2004, 2002a, 2002b, 2001; Gurtekin and Mahdavi 2003). The various dimensions of this space can represent salient design variables and relevant performance indicators. Despite the loss of some design information resulting from such representational formalisms, they could be effective in exploring the general performance implications of alternative designs.

The selection of the essential design variables and their numeric definition is a critical part of the proposed approach. Various candidate design variables must be tested in view of their "expressive" potential and the most expressive ones could be used during the alternative design generation phase. Generally speaking, building design variables capture either geometric or non-geometric (semantic) information of the building. Instances of semantic design variables are, for example, thermal transmittance of building envelope elements, shading coefficient and visual transmittance of transparent building enclosure elements, thermal mass of building fabric, and internal gains (due to people and equipment). Whereas most semantic design variables can be expressed in scalar terms, building geometry cannot be easily reduced to values of a set of scalar variables.

As such, hi-fidelity descriptions of buildings' geometry require extensive information. Moreover, design iterations that involve geometric modifications typically result in considerably time-consuming modeling efforts. There have been thus a number of efforts to express geometric design information in terms of scalar values. Some familiar scalar indicators of building geometry are: The ratio of a building's length to its width (plan aspect ratio), the floor-to-floor height, the ratio of a space's height to its depth, the ratio of glazing area to the facade area, and the ratio of the glazing area to floor area (for rooms). Most of these indicators are rather limited in their scope and applicability. This implies the need for improved aggregate descriptors of building geometry. In an effort to develop better aggregate descriptors of building geometry, Mahdavi introduced the geometric variable "Relative Compactness" (RC) (Mahdavi and Gurtekin 2004, 2002a, 2002b, 2001). The Relative Compactness of a shape is derived by comparing its volume (V) to surface (A) area ratio to that of the most compact shape with the same volume. The most compact shape in geometry is the sphere. Hence:

$$RC_{sphere} \cong 4.84 \times V^{2/3} . A^{-1}$$

As most buildings display orthogonal polyhedronal shapes, it may be more prudent to use cube (the most compact polyhedron) as the reference shape:

$$RC_{cube} = 6 \times V^{2/3} . A^{-1}$$

3. GENERATION AND NAVIGATION OF THE DESIGN-PERFORMANCE SPACE

Given a well-specified design-performance space, an initial design or an existing building can be used to generate a large number of design or operation related variations. In a previous study, we demonstrated that such large sets can be made subject to rapid performance assessment using neural network surrogates of numeric simulation algorithms (Mahdavi and Gurtekin 2002, 2001; Gurtekin and Mahdavi 2003). In this approach, a mathematical model that represents the relationship between design variables and the performance attributes is constructed. To obtain sample data needed for this model, parametric performance analyses can be applied to a number of paradigmatic instances, which are used for extensive parametric analysis and generation of a mathematical building performance model.

In previous research, we used the variations of the initial design and their corresponding performance attributes, to construct a design-performance space. This space could then be explored using data visualization tools. Thus, the designer was enabled to visualize various views of the solution space and to study the relationship between design variables and resulting performance attributes.

For the purposes of supporting climatically sensitive building design and operation support, a variant of the above approach is under development. The corresponding use case is as follows (see Figure 1):

a. The initial building model (proposed designs or existing buildings) is entered into the system by the user.

b. The resulting performance (specifically, indoor climate parameters) are instantaneously computed using the connectionist tool engine and displayed in terms of intuitive visualizations (for instance, pychrometric charts).

c. The user can manipulate the values of core geometric and semantic design variables via the application's interface.

d. The consequences of design variable modifications are mapped into new values of the performance indicators, which are again visualized.

e. In addition to step-wise modifications, users have the option to define specific ranges for design variable values.

f. Design variable ranges are mapped into corresponding performance indicator ranges, which are subsequently visualized in terms of a design-performance landscape.

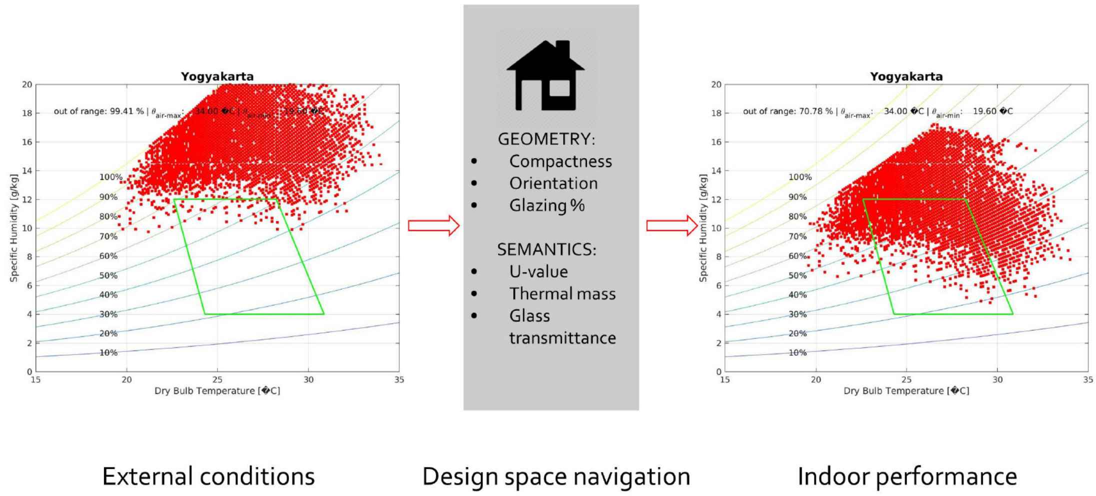

Figure 1

Fig. 1
Schematic illustration of the key functionality of the proposed tool (translation – and psychrometric visualization – of external climatic conditions into indoor climatic indicators via parametric consideration of geometric and semantic design variables). (Graphic: Pont)

4. NOTES ON THE APPLICATION CONTEXT INDONESIA

The efforts to generate the above described approach currently embedded in the framework of the Tra2in project (Transformation of Traditional Architecture in Indonesia), which targets the foundation of an interdisciplinary research center on Indonesian Architecture. This context offers a set of opportunities and challenges:

- Indonesia's climate can be generally characterized as hot and humid. Thus, efforts to provide comfortable indoor climate conditions are of high relevance. Figure 2 illustrates – as an example –the seasonal temperature distribution in Yogyakarta, Indonesia. The distribution indicates clearly the necessity to mitigate the effects of outdoor conditions on interior spaces. Contemporary building planning often relies on energy-intensive cooling strategies. Moreover, Indonesia features a large number of very diverse micro-climates, given the country's morphology, its standing as the world largest Island state, and the biannual succession of dry and wet seasons. Furthermore, Indonesia is considered to be one of the countries directly affected by the effects of climate change. Hence, climate adaptive strategies and methods to evaluate such strategies are of crucial importance.

- Indonesia's architectural heritage is characterized by a large variety, which can be seen as the consequence of different socio-cultural and religious currents as well as adaptation to local climatic influences and building construction traditions. Existing building traditions represent historically important heritage. However, a direct one-to-one adaption of such building traditions in contemporary architecture may be neither realistic nor desirable. This is due to a number of reasons, such as changes in life style, developments regarding construction materials and technology, as well as the radically different urban context. Nonetheless, careful analysis of traditional passive measures toward bio-climatic design can offer valuable inspirations for contemporary building design. An impact assessment of different design features on indoor climate, performed via the proposed environment, will offer an inexpensive and efficient evaluation methodology.

- Indonesia's islands are located on the pacific ring of fire. Therefore, recurrent natural disasters (volcano eruptions, Tsunamis, earthquakes) have to be taken into consideration in building and urban planning. This, together with the overall stress of a hot and humid climate, results in need for frequent building reconstruction and retrofit activities. At the same time, this offers the opportunity for faster overhaul of the building stock. In other words, the implementation of new design ideas into the existing building planning and delivery patterns could be accelerated. From this point of view, design support tools, such as the proposed environment, can be particularly helpful. Previous research efforts have already illustrated the potential of the integration of performance aspects into building retrofit (e.g., Museum Affandi in Yogyakarta, as illustrated in Herbig et al. 2016).

- Indonesia is considered to be a country in change. Elias and Noone (2011) state that its economy – despite the economic crisis of 2008 – still follows the strong economic growth of the past decades and continued large investments in infrastructure can be expected. Furthermore, Ellis (n.d.) indicates a strong urbanization tendency in Indonesia. For instance, the fraction of urban population in West Java is expected to increase from its current value of 60% to about 80% by 2025. Needless to say, identification and assessment methods for passive cooling methods and building designs that reduce the required operational energy can be considered as highly desirable.

- The proposed collaborative research activities in Tra2in can offer valuable synergies. In case of the proposed decision support strategy, the research foci (linked data, photogrammetry, data visualization, cartography) of the collaborators of the Center can contribute to a more versatile computational environment. Moreover, general building documentation work and architectural history research by further contributors to the Center are expected to provide important insights and valuable contributions in terms of case study buildings or monitored data.

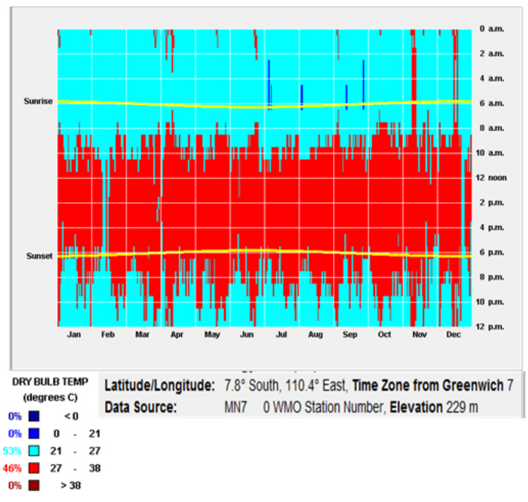

Figure 2

Fig. 1
Seasonal Temperature distribution (dry bulb temperature) in Yogyakarta, Indonesia. (Graphic: Pont)

Conclusion

In this contribution, we briefly outlined an approach to bring together knowledge-based design strategies (inspired by key features of traditional architecture) with state-of-the-art computational building performance assessment methods. The resulting synthesis is expected to provide effective methods and tools for professionals and stakeholders involved in the construction and retrofit of climatically responsive built environments.

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