TOWARD A UNIFIED INFORMATION SPACE FOR THE SPECIFICATION OF BUILDING PERFORMANCE SIMULATION RESULTS

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ABSTRACT

We present a framework for the specification of building performance simulation output results. Toward this end, we describe a simulation output space, whose primary dimensions include scalar and vector attributes, spatial destination, temporal destination, and aggregation method. We then test the corresponding matrix empirically, by considering a number of performance simulation applications for thermal, lighting, and acoustic analysis. We demonstrate how the simulation results generated by these applications could be conveniently accommodated in the proposed performance output space. We conclude the paper with a demonstrative user interface prototype based on the proposed simulation output space dimensions.

INTRODUCTION

Many researchers have dealt with visualization of scientific information in general (Tufte 1990, 1983, Tullis 1991) and the visualization of building performance simulation in particular (Prazeres and Clarke 2003, Mahdavi 2004, Mahdavi and Gurtekin 2002, Mahdavi et al. 1997). The present paper is, however, not so much concerned with the information representation and visualisation as such. Rather, we deal with the information processing stage before the point where data visualization becomes an issue. Our concern is, in other words, the provision of a systematically structured information space to accomodate data generated by building performance simulation applications. The availability of such a well-formed information space is, in our view, a necessary precondition for subsequent effective data presentation and visualization steps toward simulation-based performance-responsive building design support.

Different building simulation tools offer very different options to users in defining what analyses should be performed and what results should be generated. Moreover, simulation results are generated in a multitude of ways concerning dimensions, units, underlying aggregation procedures, numeric expressions, and visualization formats. The manifold types of building performance simulation studies and the variety of the associated outputs can hardly be subsumed into a few basic categories. However, an attempt to streamline the specification of the performance simulation output space could potentially yield a number of benefits in view of the usability of performance simulation tools:

First, a uniform performance output space would simplify the categorization and comparison of tools and the declaration of their capabilities and coverage. Second, given a harmonized output specification framework, it would be possible to more efficiently re-apply the experience made by one tool in learning and using other tools. Third, the explicit specification of the dimensions of the performance output space could facilitate the development of more flexible user interfaces for formulating a variety of performance queries based on organized multiple simulation runs. Fourth, such a uniform framework would allow for the effective adaptation of generic information visualization applications in performance simulation tools, thus providing more scalable interfaces for navigation of the simulation results space.

Given the importance of this topic and the paucity of related prior work, this paper merely attempts to provide a starting point for explorations in structured and effective information spaces for representation of building performance simulation results. Specifically, we present and test a framework (a kind of information matrix) for the specification of building performance simulation output results. Toward this end, we first constructed a simulation output space, whose primary dimensions include scalar and vector attributes, spatial destination, temporal destination, and aggregation method. To arrive at these dimensions, we "reverse-engineered" a limited number of commonly used performance indicators toward extraction of shared features that could be generalised in terms of an information matrix. We then proceeded to test this matrix empirically, by considering a number of typical performance simulation applications (available commercially or as research tools) for thermal, lighting, and acoustic analysis. A detailed study of the simulation results generated by these applications showed that they could be conveniently accommodated in the proposed performance output space. Moreover, the matrix underlying this could be used to capture the desired simulation output together with the kind and range of associated numeric or graphic expressions.

We conclude the paper with a demonstrative user interface prototype based on the proposed simulation output space dimensions. We describe how such an interface can improve the process of specifying building performance queries and expressing their outcome.

APPROACH

Performance simulation output space

The proposed generic matrix is meant to capture the essential dimensions of numeric information space generated by performance simulation applications. As shown in Table 1, this matrix involves three main dimensions, i.e. magnitude, spatial extension, and temporal extension. The magnitude is expressed in terms of a scalar and – if applicable – a vector component and is specified via a proper unit. The spatial extension may be expressed, for example, in terms of a point, a plane, or a bounded volume (space) in a building. Moreover, the spatial resolution of the output information may be specified in terms of a grid. The indication of the mode of summation (or averaging) of the indicator's magnitude over space rounds up the specification of the spatial extension of performance simulation output information. As to the temporal extension of the indicator attributes, the duration and the resolution (the size of the time steps) of the simulation period must be specified, along with the mode of temporal aggregation (summation, averaging, etc.) of a performance indicator's values over a number of time steps. Table 1 provides a summary of the above dimensions together with typical performance simulation output examples (heating load, room temperature).

Applications

In order to test the general validity of the proposed matrix (see Table 1), we selected eight performance simulation applications. An attempt was made to include in this sample applications of different analysis domains (thermal, acoustical, visual), different levels of algorithmic complexity (from simplified procedures to advanced numeric engines), and different output formats (text, graphics). Some general information regarding these applications is provided below. A summary of application domains is given in Table 2 (application names are excluded to avoid commercialism). Applications "B", "D", and "E" are research tools. Applications "C", "F", "G", and "H" are commercially available. "A" is a public share application.

Table 1
Dimensions of the proposed information matrix for the unified representation of performance simulation results

Performance output dimension		Heating load	Temperature
Magnitude	Scalar component	10.1	25
	Vector component	-	-
	Unit	kW	°C
Spatial extension	Point	-	-
	Plane	-	-
	Bounded volume	Room 1	Room 1
	Resolution (grid)	-	-
	Aggregation mode	-	
Temporal exten.	Duration	Day 15	Hour 12, Day 195
	Resolution	1 h	1 h
	Aggregation mode	Arithmetic averaging	-

Application A is a calculation program to estimate building monthly heating load and predicted energy use values. It is conceived mainly for use as an educational tool. Application B supports the computation of solar data (sun position, direct and diffuse irradiance values, etc.). Application C combines a number of tools for computations in thermal (hourly temperature and energy use data), acoustic, and illumination domains. Application D, E, and F apply numeric methods to compute hourly energy use and room temperature data. These three applications differ, however, in the level of computational resolution and the range of graphic support for data visualization. Finally, application H is a comprehensive tool that uses an advanced ray-tracing method to support room acoustic computations and auralisation.

The entire set of performance output options that can be obtained using the above-mentioned eight simulation applications was collected and tested in view of its compatibility with the proposed general matrix for the specification of building performance simulation results (cp. Table 1).

Table 2
Selected application with corresponding applicable performance indicator domains and result presentation mode
(t: text, g: graphic, g: limited graphic)*

	Applications							
Performance domains	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Thermal data	✓	-	✓	✓	✓	✓	✓	-
Solar data	-	✓	✓	-	-	-	-	-
Visual data	-	-	✓	-	-	-	-	-
Acoustical data	-	-	✓	-	-	-	-	✓
Visualization mode	g	t, g,	t, g	t, g*	t	t, g	t, g	t, g

RESULTS

As mentioned before, we reviewed the entire set of output options (building performance simulation results) that can be generated using the eight performance simulation applications considered in this study (see Table 2). We then examined if some or all of these output options could be presented within the framework of the proposed generic matrix (see Table 1). Table 3 shows, as an example, the output options of the application E, structured in terms of the proposed matrix.

Table 3
Matrix-representation of the performance indicators computed by application E (mo: month; a: year)

Performance output dimension		Heating load	Heating/ cooling/ electrical energy use	Tempera-ture
Magn.	Scalar component	✓	✓	✓
	Unit	W	kWh	ºC
Spatial ext.	Point	✓	✓	✓
	Volume	✓	✓	✓
	Grid res.	1 m	1 m	1 m
	Aggregation	Arithm.	Arithm.	Arithm.
Temp. ext.	Duration	h	mo, a	h
	Resolution	1 h	1 h	1 h
	Aggregation	-	Sum	-

Table 4 summarizes the main results of the study. It includes, for each application: *a)* the number of output options that can be generated using this application, and *b)* the number of options that can be captured in terms of the dimensions of the proposed performance output matrix. The table includes also the corresponding percentages of output options that can be expressed within the framework of the proposed matrix.

Table 4
Total output options of the eight applications together with the corresponding number of output options that can be expressed in terms of the proposed general simulation output matrix

Application	Number of output options	Number of options compatible with matrix	Percentage of options compatible with matrix [%]
A	8	8	100.0
B	13	13	100.0
C	92	84	91.3
D	11	11	100.0
E	5	5	100.0
F	18	18	100.0
G	3	3	100.0
H	19	16	84.2

As it can be seen from Table 4, the bulk of the performance simulation results generated by the eight applications considered in the present study can be readily captured in terms of the dimensions of the proposed matrix. Nonetheless, a few output options (cp. Applications C and H) cannot be captured in terms of the dimensions of the proposed general matrix for numeric simulation results. A close look at these options reveals, however, that they belong to a specific class of visualized information that may be labelled as "analogue". The two main instances of such "analogous" representations include "pictorial" outputs (such as computer-generated renderings of architectural scenes) and "symbolic" (typically graphic) outputs. To the latter category belong, for example, depictions of light and sound propagation and reflection patterns in spaces (cp. Figures 1 and 2).

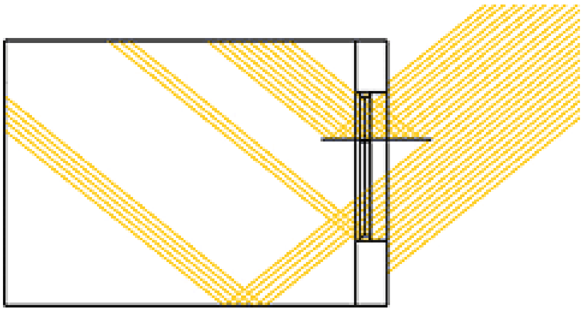

Figure 1
Sun rays entering into and reflecting inside a space depicted by application Ecotect (2004)

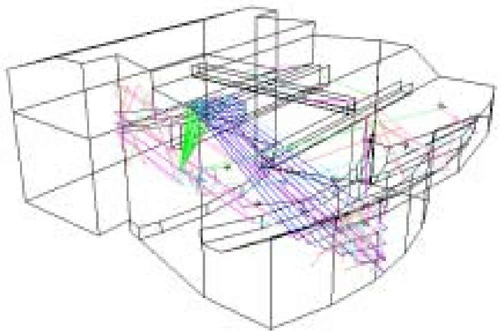

Figure 2
Depiction of sound propagation in a space generated by application Ecotect (2004)

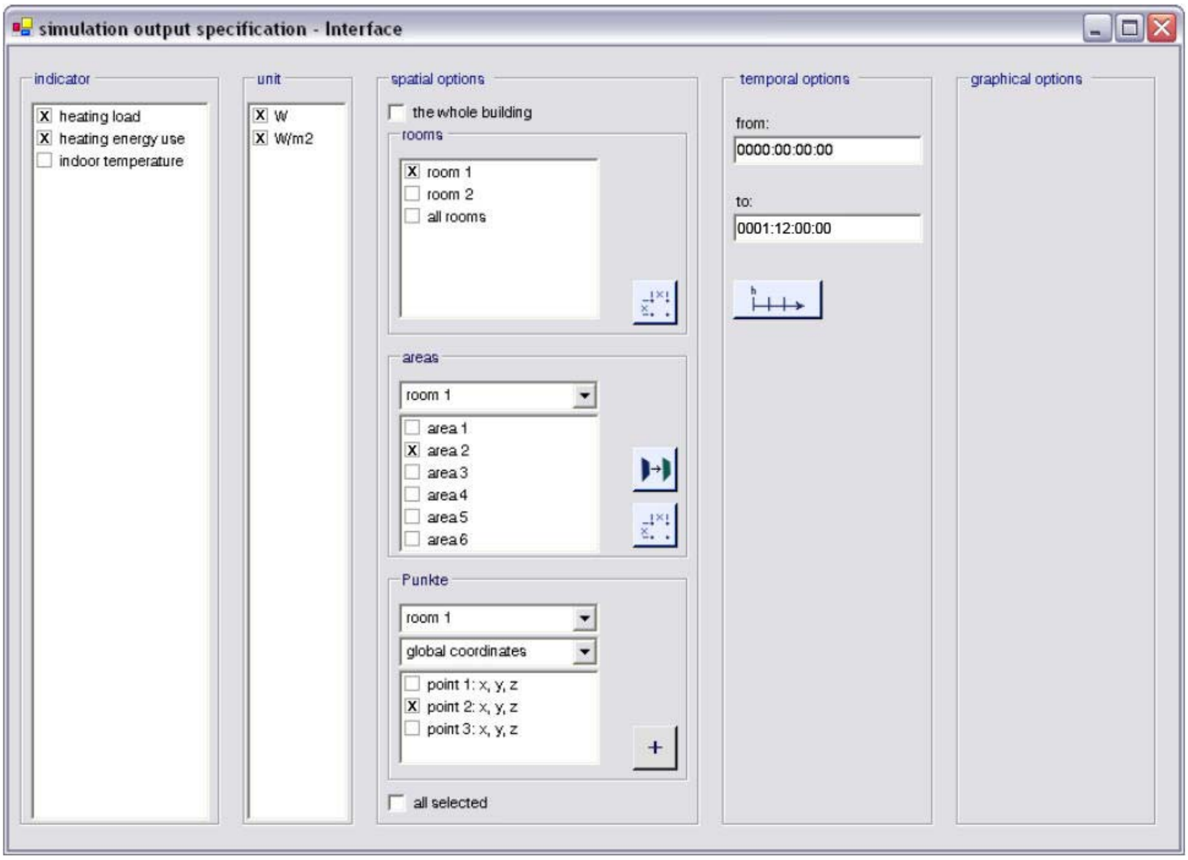

Figure 3
Illustration of a prototypical user-interface for the specification of a performance query based on the structure of the proposed simulation output matrix

A DEMONSTRATIVE INTERFACE

As we argued in the introduction to this paper, a unified matrix for the representation of building performance simulation results can, amongst other benefits, provide an effective basis for the communication between the user and the simulation applications. An interface that is based on this matrix can support a systematic process toward the communication of specific performance simulation queries to simulation tools. To illustrate this possibility, we implemented a simple prototypical interface (see Figure 3), which can support a typical performance query specification procedure involving the sequential specification of *i)* performance indicator; *ii)* unit; *iii)* spatial extension; and *iv)* temporal extension. This prototypical interface illustrates how a user can communicate with a simulation application using the dimensions of the proposed matrix.

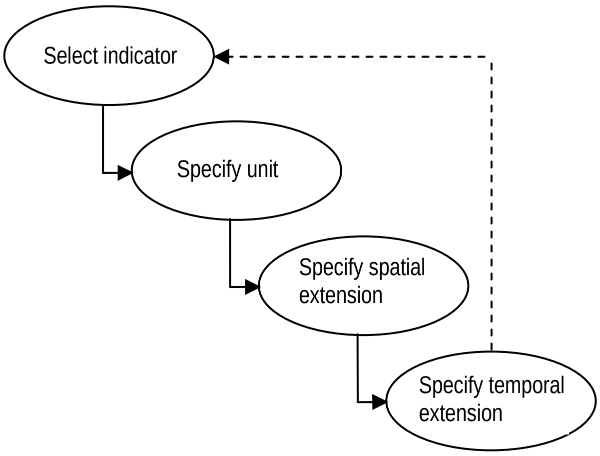

Figure 4
The basic performance query procedure supported by the prototypical interface (cp. Figure 3)

CONCLUSIONS AND LIMITATIONS

The multitude of currently available performance simulation tools provides a broad range of simulation results. Moreover, these results are computed, formatted, and presented in very different ways. In this paper, we hypothesized, that the multiplicity of output specification could be organized into a unified information matrix with a few, distinct dimensions. Such a matrix was derived and tested against the actual performance simulation result types of eight simulation tools. This showed that the proposed matrix can effectively accommodate all but one category of simulation results, namely "analogue" (pictorial, symbolic) output. Moreover, a preliminary exercise in interface development implies that users could efficiently specify desired performance simulation results along the dimensions of the proposed information matrix.

As this paper represents exploratory work, we would like to emphasize a number of limitations of the work to date:

First, the form of argument for the validity of our proposed matrix is deductive. We have not derived the necessity of the inclusiveness and conclusiveness of this matrix on the basis of – necessarily true – logical arguments, but based on a test using eight applications. Thus, the universal validity of the matrix could be refuted by providing a counter-example. Other than the previously mentioned class of analogue results, we could not identify any counter-examples.

Second, we do not claim that the provision of a unified information matrix would or could resolve the problems of tool communication and interoperability. Even if all simulation applications would adapt the proposed matrix, they still could format the respective data files in exclusive and proprietary data formats, thus hindering the interoperability of output documents. The proposed matrix would support a "semantic" interoperability. Using the matrix, the tools would explicitly declare the dimensions of their output (not only magnitude and unit, but also the resolution and modes of temporal and spatial aggregation), thus supporting a unified basis for user-tool communications pertaining to the specification of simulation results.

Third, the interface prototype discussed in the previous section is not meant to represent a desired generic tool for performance simulation output specification for all applications. Rather, it is merely meant to provide a starting point for the exploration of the degree to which user interactions with simulation tools can be more effectively organised based on the proposed information matrix. Our experiences to date show that the specification efficiency of desired performance simulation output by the user can be increased regarding magnitude and temporal extension. We intend to improve the usability and versatility of this interface in the future, particularly in view of supporting the specification of the spatial extension of performance output through the services of a computational tool for the navigation of the building geometry model.

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