A METHOD FOR MULTIPLE-VIEW ASSESSMENT OF BUILDING PERFORMANCE IN ESP-R

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ABSTRACT

This paper presents the requirements of the building representation to supports the holistic performance assessment of building performance into a single application. The performance views considered are energy consumption, room acoustics, occupant comfort, and the life cycle impact assessment related to the fuel and materials flows over the whole building life (LCIA). The paper continues with the description of this data model into ESP-r, an existing advanced building simulation application, and its extension to support room acoustics and LCIA views.

Keywords: Integrated performance simulation; Life cycle analysis; Data modelling; Building design

INTRODUCTION

With the advent of personal computers and communication technologies, several approaches have been developed to take up the challenge of multiple-view simulation of the building performance. From the viewpoint of simulation capability, four program categories can be identified, ranging from fastidious to easy-to-use:

- **Stand-alone** (single assessment view) programs are the most basic solution for multiple-domain simulation. In this approach, *unrelated* programs are used for a multiple-view simulation. This obliges the user to create one project model per application
- **Interoperable** programs provide a procedure whereby different computer tools can exchange and/or share information. The model transfer is only possible at the application invocation level, which does not allow a dynamic data exchange between applications during the simulation process itself. As with the stand alone approach the user is required to master each program’s interface. For interoperable applications, simultaneous transaction management is an important issue to solve .
- **Coupled** (or linked) programs provide the facility to link applications at run-time in order to co-operatively exchange information. Generally, one application controls the simulation and calls the other application(s) when necessary. Only the simulation engine of the coupled program(s) is required
- **Integrated** programs provide a facility to simulate different domains within the same program using a single data model.

The main advantage of the coupled and integrated approach is that it supports the dynamic exchange of information during a simulation. It allows to check dependencies within the single (more complex) model than would typically be possible with stand-alone programs. Data management is simplified as only one model is needed to run multiple-view simulation. Changes could be made more easily and better managed, and verification become simpler. Any project modifications need only to be implemented once. Another advantage of both approaches is the singularity of the front-end, which ease the learning process.

Compare to the coupled approach, the integrated solution does no required any exchange file format and the evolution of the application is made easier because it does not depend on external application(s).

The integrated approach simplifies the checking of the model consistence and application development. It offer benefits regarding the exchange of performance information between analysis domains during the solution process. For holistic approaches, which rely on the interaction between all aspects of a design, such exchanges can be critical, and therefore the integrated approach may better meet the requirements of multiple-view assessment.

BUILDING REPRESENTATION

A consistent and comprehensive building data model is required to perform an integrated assessment of building performance where the domains can be disconnected, loosely connected or dynamically connected. The purpose of the proposed data model is to support the creation of a building representation for a multiple-view analysis of buildings. The key issues to be addressed include data model completeness, elimination of redundancy, maintenance of consistency as well as application and technology independence.

The geometrical representation of a building component does not give any information on the corresponding material properties. This entails the building geometry/topology to be independent of its physical properties and both representations to be decoupled. Clearly, many entities within the geometry may have identical physical properties. If each geometric entity included all of the physical data then there is considerable redundancy in the model. If, however, each geometric entity includes only the names of its physical information attributes(i.e. a pointer) then the two information types can be decoupled.

The information required to create a computer representation of a building can therefore be separated into:

- the *geometry* information, which holds for instance the dimension, the orientation, and the connections of a component; and
- the *construction* information, which holds the physical properties of the constituting material(s), such as the density and environmental impacts.

Both models are independent and linked by an attribute that connects the geometry of a building constituent to its physical representation as shown in Figure 1.

Separating the geometry/topology model and the physical model has several advantages in terms of data consistency and model extensibility. If the physical and geometry model are merged, maintenance becomes more complex. For example, to update the value of a physical property, it is necessary to find each occurrence of that property in the model, which can be a time consuming process in cases where the data model is large. Separating the geometry and physical model eases the maintenance and consistency of the building model in the sense that the physical information related to a material or a construction is stored in only one place. Therefore any modification of a property also needs to be performed only once.

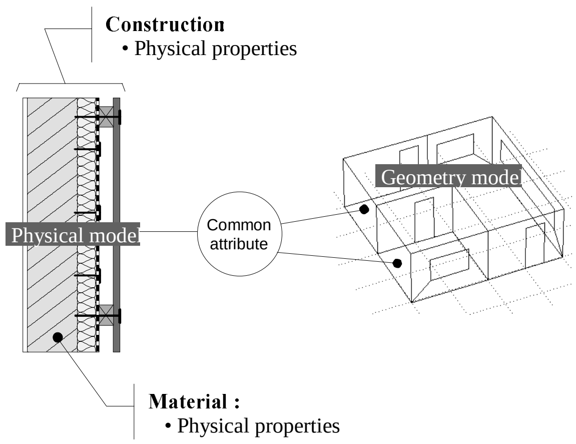

Figure 1 Abstract representation of the separation between geometry and physical model.

Although building performance can be appraised based on a limited number of the properties, there is currently no unified method allowing a multiple-view assessment based on basic material properties. For example, the material properties required for a lighting simulation do not provide any information on the environmental impacts of the material. Therefore, for each considered view, the corresponding physical properties must be included within the physical data model. This latter is therefore segmented into physical views. It stores for each view one set of physical properties. The construction, made of one or several materials is then linked to the geometry model.

DATA MODEL STRUCTURE

The *Construction* entity holds the information at the construction level and records attribute for different views plus the layer composition. Each construction is univocally defined by its *Construction name*, which is used as the connecting attribute with the geometry representation of an element.

Each construction side (inward and outward) has a *Photo-colourimetry* and a *Acoustic absorption* set of attribute, which are used to refer to physical information respectively for lighting and room acoustics views. The construction can also holds a set of *environmental impact attributes* which refer to information at the construction-level (required for prefabricated element). Transparent construction may have optical information referenced by its *Optics*. Finally, a construction consists of one or more *Layer(s)* defined by a *Material name* and its corresponding *Thickness*. The material information includes the attributes related at the material-level as shown in Figure 2 which uses the NIAM conceptual modelling language [17]..

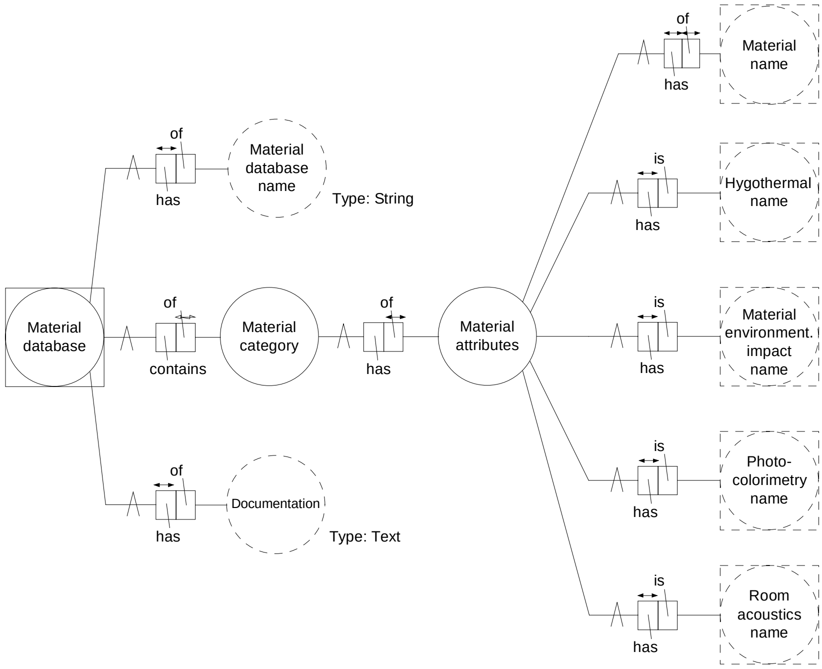

Figure 2 Material attributes diagram

It includes the *hygro-thermal*, the *photo-colourimetry, environmental impacts* and the *acoustic absorption* attributes. Each material is univocally defined by its *material name*.

PHYSICAL PROPERTIES

The selection of physical attributes is limited to elementary properties which cannot be derived from other more elementary properties. For instance, effusivity is not an elementary property because it can be derived from the density and the conductivity, which are elementary attributes. The physical information required by a calculation method, but which is not related to the building element, is not taken into account. For example, some advanced day-lighting methods require the sky luminance distribution. As this property is not directly related to the construction materials, it is not included here.

As the data model becomes more exhaustive for a particular view, it will tend to become assessment method independent for that view [2]. Were the data model to include all possible information, there would be no need for a specific view to complete its local data model by adding supplementary information. Therefore, the physical model should include a set of material properties that is as exhaustive as possible, which should be seen as a simplification for future integrated simulation developments.

The following physical properties were selected in order to support the appraisal of the building energy consumption (heating, cooling, ventilation, lighting), room acoustics and the life cycle impact assessment (LCIA):

<u>Hygro-thermal:</u> Density, solar absorption, emissivity, conductivity, vapour diffusion resistance, specific heat

<u>Photo-colourimetry</u> : Reflectance, chromatic co-ordinates, surface roughness and specularity

<u>Room acoustics</u>: Acoustic absorption coefficients (1 octave band)

<u>LCIA</u>: Service life, specific impact for material fabrication, working-up, maintenance process and the loss rate during the material assembly. For each

material transport: the transport impact, distance and breakage rate. For each possible disposal process, its rate for the material and the corresponding impact.

IMPLEMENTATION

To demonstrate the feasibility of the proposed approach, the presented data model has been implemented into an existing building simulation program, in which the physical data model was implemented and its functionality was extended to support the assessment of missing views.

As a result of a selection procedure, ESP-r [3], a transient energy simulation system, capable of modelling energy and fluid flows within combined building and plant systems. ESP-r was selected because it include the current state-of-the-art in building simulation, is recognised in the scientific community, is still under sustained development and supports an open architecture, which offer free access to the necessary source code. Finally, its flexible and modular structure facilitates the development and implementation of new views.

In ESP-r, the 3D geometry model representation is based on a common model hierarchy, in which the building is represented as a grouping of *zones* (bounded volume). Each enclosing surface has a *Surface name*, a *Boundary condition* (exterior, contiguous zone, adiabatic, etc.) and a *Construction name* attribute. The latter is used to link the geometry model and the corresponding construction representation.

The assessment views originally supported by ESP-r have been extended with two new views. The first view enable the assessment of the environmental impacts generated by the construction materials and processes used over the building life. The second view permit to assess the room acoustics in an enclosure.

ENVIRONMENTAL IMPACTS

The goal of the building life cycle impact assessment (LCIA) is to estimate the potential effects on the environment that are generated by a building during its entire building life, from cradle to grave. The developed methodology is based on the framework proposed by the international organisation for standardisation (ISO) [9].

The building contributions are related to the use of materials and processes during its entire life and the energy consumed during its utilisation phase. To take account of all these environmental impacts, a detailed analysis of the life cycle phase occurring during the building life was undertake. It takes into account the impacts generated by the construction materials fabrication, transport and processes during the building construction (including material breakage during the processes), maintenance, replacement and deconstruction, as shown in Figure 3.

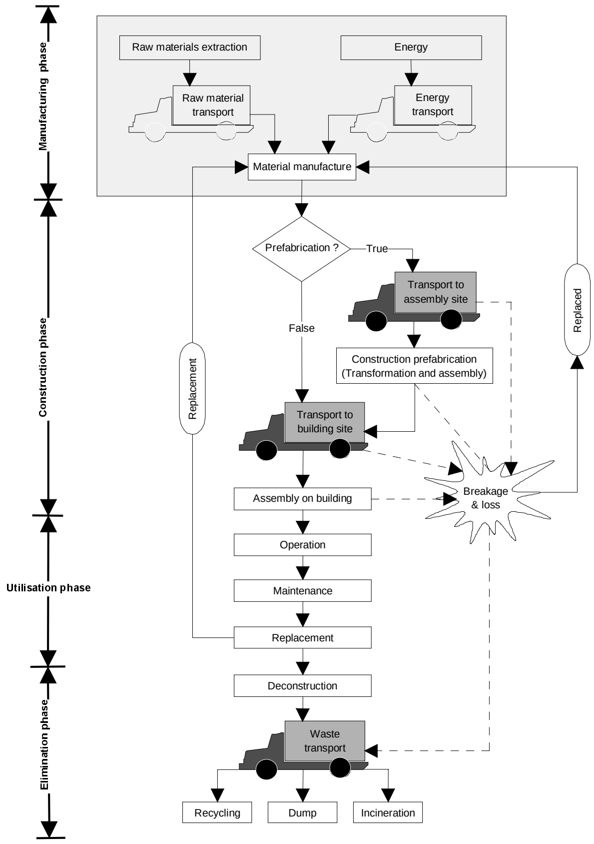

Figure 3 System boundaries for the building LCA.

The energy consumed during the utilisation phase can be assessed (primary goal of ESP-r), converted into equivalent impacts and added to the previous environmental impacts to provide a comprehensive environmental profile of the building. The LCIA of a building results with a set of environmental indicators (eco-profile).

In addition to the primary energy obtained from non renewable sources, three environmental effects were retained as indicators for a building LCIA, which have been selected among the environmental effects proposed by Heijungs [8] in the CML[1] method, that are:

- Non-renewable energy (NRE)
- Global Warming Potential (GWP)

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[1] Dutch abreviation for Center of Environmental Science (part of Leiden Unervisity, the Netherlands)

- Acidification Potential (AP)
- Photochemical Ozone Creation Potential (POCP)

Although it has not been considered here, the presented approach supports the use of any environmental indicator, such as Eco-indicator 99 [7], EPS [19], or a mix of them.

The LCIA of the project correspond to an iterative calculation over all the elements define within the geometry model. The interface returns a set of environmental indicators (eco-profile), which can be display at various level of detailed ranging from one set of metrics for the whole project to one set for each material, in each construction, at each life cycle phase for a detailed analysis as shown in Figure 4.

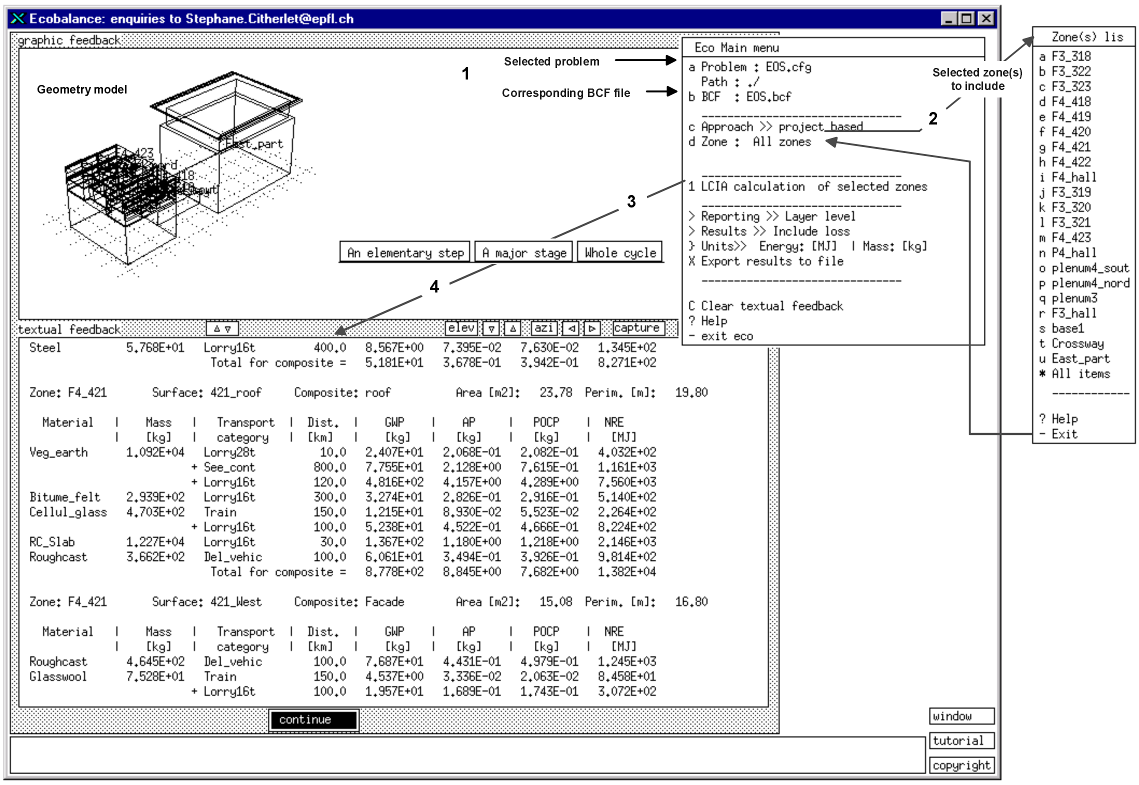

Figure 4 LCIA interface implemented in ESP-r

ROOM ACOUSTICS

Several indicators might be used to assess the room acoustics performance. The *reverberation time* has been retained to demonstrate the feasibility of the integrated approach as it is a well known metric to assess the room acoustics. The reverberation time calculations implemented in ESP-r correspond to three versions of the diffuse-field theory: the Sabine [18], Eyring [4], and Millington [16] equations.

The reverberation time of the enclosure includes the absorption due to the boundaries, the furniture and the occupants. The boundaries area are extracted from the 3D geometry model of ESP-r and the physical information (absorption coefficients) are extracted from the constructions data model. The furniture and occupants information is recorded at the enclosure level.

To improve the reverberation time calculation, the dependence to the air temperature and humidity of the speed sound and the air absorption have been taken into account and are derived from the calculation of the sound attenuation coefficient defined in [10] and Lienard works [15].

The theoretical model from which the Sabine, Millington and Eyring equations are derived requires that the decaying sound field be perfectly diffuse, which is not necessary achieved in an architectural space. To refined the room acoustics assessment, several other approaches based on the diffuse-field theory could be implemented to estimate the reverberation time, such as [1,6]. The physical data model developed for the room acoustics does not limit the calculation methods to analytical solutions, but also support also simulation methods such as image source [13], ray-tracing [12], cone/pyramid tracing [5] and Hybrid [14], [20].

The room acoustics interface in ESP-r enable to select a zone within the geometry model and return the reverberation time and additional information such as the equivalent surface. When a building is modelled, a thermal zone generally corresponds to an enclosure delimited by building elements, in which some parameters, such as the air temperature, are uniform in that delimited volume. For instance, an office room might be modelled as a single thermal zone. In this case, the acoustic zone boundaries correspond to the thermal zone boundaries and the volume used to assess the reverberation time is equal to the volume delimited by the thermal zone.

For a thermal simulation of a large space, such as an atrium, the enclosure might be separated into several smaller thermal zones to assess the distribution of air temperature as a function of height. In this case, the volume is segmented in a superposition of thermal zones. In such cases, the surface contiguous to two thermal zones is defined as an element that does not have hygro-thermal properties. This «fictitious» surface does not influence the thermal analysis.

To assess the reverberation time of such a large space, made of several thermal zones, the philosophy is to store for this «fictitious» surface, absorption coefficients equal to zero at each frequency. With this approach, the acoustic volume is equal to the sum of the thermal volume and the surface included in the calculation corresponds to the surfaces of all thermal zones as shown in Figure 5. And as the fictitious surface does not absorb sound by definition, the contiguous surfaces are not taken into account in the calculation of the equivalent area.

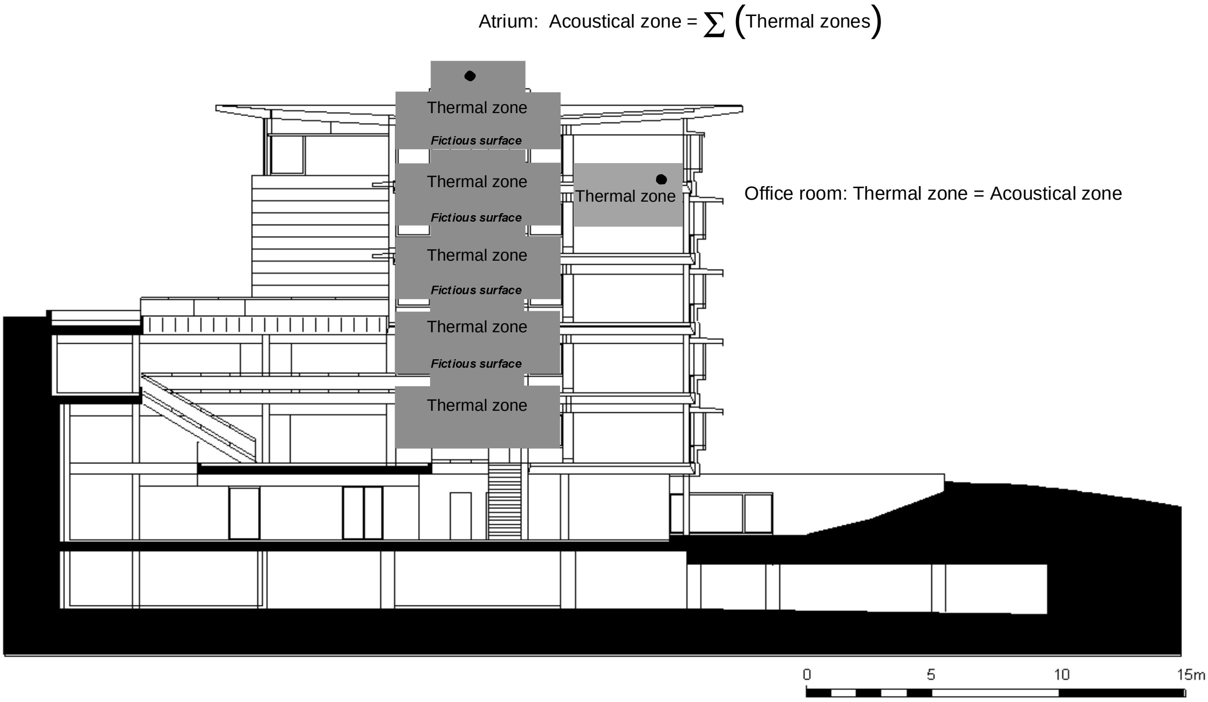

Figure 5 Thermal and acoustic zone representation in the case of an office room and an atrium.

When the aperture between two zones becomes small compared to the contiguous surface area, then the zones should be regarded as coupled spaces. In that case, the reverberation time calculation as proposed previously will not provided accurate results. Future developments might consider to improve this calculation based on methods such as proposed for instance by Jouhaneau [11].

CONCLUSIONS

The developments presented in this paper are dedicated to the elaboration of an integrated application, in the sense of a unique simulation tool, which does not require information sharing or exchange with other applications, enables the multiple-view assessment of building performance and the environmental impacts generated by the building during its entire lifecycle. According to the previous considerations, the data model developed relies on the following principles**:** (1) Decoupling of geometry and constructions information, (2) Supports a life-cycle decomposition. (3) View decomposition, which enable a multiple-domain assessment of the building,

The presented model was implemented into ESP-r, an advanced transient energy simulation system. With this comprehensive data model, it supports the assessment of the building performance, including the room acoustics and a comprehensive life cycle impact assessment generated during the building life.

An other paper presented by the author in this conference is dedicated to the utilisation of these developments to analyse the performance of an existing office building.

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