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# LEVERAGING BUILDING DESIGN MODEL FROM ENERGY PERFORMANCE MODEL: FROM AN IFC/BIM TO COMETH SIMULATION ENGINE

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## ABSTRACT

Dynamic building energy simulation is recognized as a pivotal component of design tool support but is also considered as a complex task, requiring specific expertise. With the take up of Building Information Modelling and of advanced Information and Communication Technology (ICT) in the Architecture, Construction and Engineering (AEC) area, there is a unique opportunity to unfold the full potential of energy simulation thanks to seamless, effective a connection between BIM design information and energy simulation data models. In this scope, and with the aim to illustrate how BIM standardization may contribute to this challenge, this paper gives an account of a research study lead to deliver and assess a framework for automated transformation of Industry Foundation Classes (IFC) models to energy simulation models. The framework includes a well-defined transformation specification process, based on the buildingSMART Information Delivery Manual (IDM) and Model View Definition (MVD), and a software tool for the generation of input files for the French thermal regulation simulation engine (COMETH) from IFC models. The paper describes the overall framework, outlines the implementation of a simple use case of a house in passive mode, and draws some lessons for future works.

## INTRODUCTION

Current building performance analysis practices rely much on BIM technologies. Nevertheless, there remain interoperability shortcomings that seriously hinder the impact of BIM and ICT tools on the effectiveness of energy analysis. To fully unfold the potential of BIM-based simulation, approaches have to be devised that allow for reliable and seamless transformation of building digital design information into simulation environments input files. This would result into significant benefits, both from the cost-effectiveness (analysis is performed more effectively) and the reliability (simulation models strictly comply with design models) points of view. However, to implement such approaches, several barriers have to be considered. The first is the need for a common, standardized BIM language. The second is the definition of adequate and standardized extension mechanisms, to customize BIM for simulation-specific purposes. The third is the provision of software tools, for effective and reliable BIM to simulation models transformation. The first barrier is likely to be overcome through the advent of the buildingSMART Industry Foundation Classes (IFC), which is widely recognized as a standard BIM exchange format in the construction industry. However, with respect to the second barrier, the IFC remains a wide-purpose modelling language and as such, fails to address many domain-specific issues, like e.g. energy simulation. This limitation has been acknowledged by buildingSMART, who have delivered novel methodological tools to allow for domain-specific customization of IFC. The main one is called the Information Delivery Manual (IDM) (Open Geospatial Consortium Inc., 2008). The IDM is dedicated to the characterization and description of building (design) processes, with a focus on the specification of information exchanges. It is particularly useful to specify heterogeneous information flows and the related inter-formats transformations. The IDM is well supplemented by the so-called Model-View Definition (MVD), also from buildingSMART, which allows for the definition of application-specific IFC subsets.

The rationale that underlies the research presented in this paper is that IFC, together with the related customization frameworks (IDM and MVD) may be the most relevant basis to implement a reliable connection between BIM and simulation, provided they are supplemented by a dedicated software support. The aim of this study is therefore: (i) to assess the applicability and relevance of IDM / MVD for application-specific uses of IFC, focusing on energy analysis; (ii) to prototype and validate a software tool for the transformation of IFC into simulation models. To this end, we have applied IDM / MVD to the mapping between IFC and the French thermal regulation simulation engine COMETH (a work which initial steps are outlined in (El Asmi et al., 2014)) and developed a software tool to automate the related transformation. This paper gives an account of this work, and of the related use case. The latter deals with a two-storeys individual house simulated in passive mode (no HVAC systems).

The paper starts with a short summary of related works. Then the methodology followed to design and implement our framework is described. The last section outlines the first results of our work, before concluding.

## RELATED WORK

The pivotal role of building design information in building energy analysis is usually not questioned, and therefore the issue of interoperability between BIM and energy models is regarded as a critical research challenge. For instance, (Laine et al., 2007) highlights the efficiency of using BIM for thermal energy simulation. Moreover, (Bazjanac, 2007) presents the importance of the use of the National Building Information Model Standard (NBIMS) in energy performance simulation. In addition, in more recent study (Bavastro et al., 2014) focuses on the importance of exchange between 3D models and the energy model and its impact on the energy demand.

Furthermore, A wide range of tools for energy simulation is available with contrasted capabilities. This is illustrated for instance by the review given in (Attia, 2011). The evaluation relies on five criteria: usability, intelligence, accuracy, interoperability, process adaptability and takes into consideration ten tools (HEED, eQuest, Energy-10, Vasari, Solar Shoebox, OpenStudio, VE-Ware, ECOTECT, DesignBuilder, BEopt). Another comparative paper (Maile et al., 2007) describes the DOE-2 and EnergyPlus building thermal simulation engines, and the related user interfaces.

Interoperability with BIM has also been addressed in several research publications. For instance, the paper from (Moon et al. 2011) gives an evaluation of the interoperability between a BIM model and different energy simulation tools such as EnergyPlus, eQUEST, Ecotect and IES<VE>. The focus is on the gbXML exchange format that encompasses building geometry, space composition, building construction, internal load, operation schedule and HVAC system. The paper shows that all these tools are compatible with BIM models but to different interoperability levels. The paper also makes some suggestions aiming to improve interoperability with the selected simulation tools.

One conclusion that can be drawn from the literature review is that EnergyPlus (U.S. Department of Energy, 2004) is one of the most popular simulation environments and that many researches aim to improve the linking between EnergyPlus and BIM. In this scope, the work of (Bazjanac et al., 2004) is foundational, for instance where an IFC HVAC interface for EnergyPlus is described. This interface, which relies on IFC property sets, allows mapping EnergyPlus input data to IFC-compliant BIM authoring tools. We can also mention the work of (O'Sullivan et al., 2005) proposing a GUI interface linking IFC models and EnergyPlus software. Other papers address the interoperability of BIM and simulation. For instance, (Kim et al., 2015) works on the development of a physical BIM library for building thermal simulation. Also (Yan et al., 2013) in his paper, works on the connection between BIM with thermal and daylighting modelling. In the same flavor, (Hitchcok and Wong, 2011) propose an IFC to EnergyPlus transformation, highlighting the fact that IFC models have to be enriched to allow for the generation of complete energy simulation models. Also, the Simergy project (O'Donnell et al., 2013) addresses BIM to BEM (Building Energy Model) transformation, thanks to a mapping process between ArchiCAD and EnergyPlus.

Other tools are worth being mentioned, for instance those delivered as part of the EBS Annex 60 Project (EBC Annex 60 Project (2012-2017)). This project brings together the contributions from around 100 researchers worldwide about a transformation process from BIM to BEPS (Building Energy Performance Simulation) based on Modelica modeling language and Functional Mockup Interface (FMI) standards. A part of this project is to fill the gap between Building Information Models and energy modeling using Modelica Libraries and link existing building performance simulation tools with such libraries through the Functional Mockup Interface standard.

The advantage of using Modelica, is its growing research community developing several modules for simulation through many research proposals. For example, we can highlight the work of (Cao et al., 2014 ; Wimmer et al., 2014) proposing a model transformation from IFC based BIM to Modelica. They focus on HVAC system conversion from SimModel to Modelica, where SimModel is used as a placeholder for IFC. It is an extensible data model for inter-disciplinary data exchange between building data and the simulation domain (O'Donnell et al., 2011).

Other research works focus mainly on geometrical issues in 3D models by proposing algorithms to perform the linking between CAD tools and simulation techniques (Van Treeck et al., 2007). In a similar scope, we can mention another algorithm (Bazjanac et al., 2013), which from a CAD model generates space boundaries for building simulation tools.

Further research works have aimed at assessing the capabilities of the IFC format, including the latest released version (IFC4). They show that cannot be the locus for the full specification of the energy simulation information (Robert et al., 2014). For instance, in our specific scope, it does not include the elements required for energy simulation in the COMETH simulation engine (Haas and Corrales, 2013). This is why some researches have been performed to leverage the design model. This is e.g. true of the work by (Cemesova et al., 2012), which presents a « passivBIM » methodology to extend the IFC schema with key energy concepts and entities.

# METHODOLOGY- DESIGN APPROACH

**Input data for Simulation**

The envisioned process (Figure 1) is as follows: the IFC compliant design tool delivers an IFC model describing the geometry of the building. The IFC model obtained is not ready for energy analysis and requires some enhancements. At this step, enrichments have to be done in order to create a building simulation model (BSM). In fact, the simulation process need in input information about the design of the building, HVAC systems (Heating, Ventilation and Air-conditioning), the external environment such as weather data and, some simulation parameters. Once this is done, one has to do some model transformations for the BSM to be compatible with the simulation engine. In fact, each simulation tools has its input format and don't necessary support IFC import.

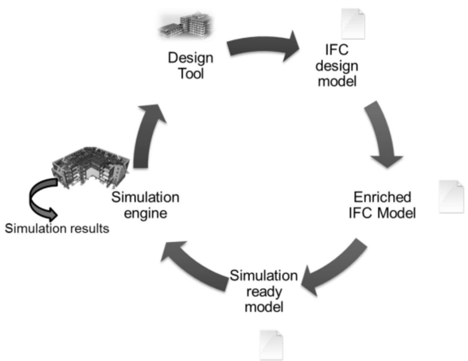


*Figure 1 General simulation process*

As a result, we obtain a simulation ready model that we can use to perform analysis with the targeted simulation engine. The simulation engine used in this work is COMETH (Haas and Corrales, 2013); it is an energy analysis and thermal program. COMETH stands for COre for Modelling Energy and Thermal Comfort; it is developed at CSTB since 2009. It does not have a graphical interface and does not support IFC model, COMETH allows calculating heat demand, to specify a ventilation model, a lighting model and the management of the openings / fenestrations of the building. As a result, it computes the building's energy consumption.

COMETH, like all simulation tools take as input many information:

- Building geometry: Defining the geometry, constructions, materials and spaces of the building; Assignment of the space objects to thermal zones;

- HVAC elements: Definition of the HVAC systems and their components;

- External environment: the location of the building site so that the model can be linked to location-specific climate information

- Some simulation parameters.

**Building Simulation Model (BSM)**

Building Smart, has proposed a set of standards: IFC, the Industry Foundation Classes, as a neutral and open specification for BIM and IDM (Information Delivery Manual) / MVD (Model View Definition) to define and structure the exchange (Open Geospatial Consortium Inc., 2008).

The information exchange framework (IDM-MVD) has the potential to improve the information exchange and decompose the targeted model that corresponds to the input data for analysis. It has already been applied.

(Jeong and al., 2014), for example, follow the IDM/MVD methodology (Figure 2) to define the translation between a building model and energy model with Modelica.

In addition, a complete documentation of using IDM/MVD can be found in the BLIS project, documenting the exchange requirement "BIM Based Energy Analysis", the whole methodology being presented here (BLIS Project, 2009). The IDM (Information Delivery Manual) is therefore a relevant support to the preparation of the input data for energy analysis. It has already been applied in the initial steps of this work (El Asmi et al., 2014), with the aim to define the exchange requirements that apply to the connection between the COMETH simulation engine and the BIM. These exchange requirements result in an MVD (Model View Definition) that describes the envisioned data exchange in a dedicated view (a subset of the model). Doing so, the energy analyst can decide which element of the IFC model maps to which part of the energy model. However, the IFC model cannot include all the information required by simulation, and the missing elements (concepts, properties) have to be defined in ad-hoc extensions.

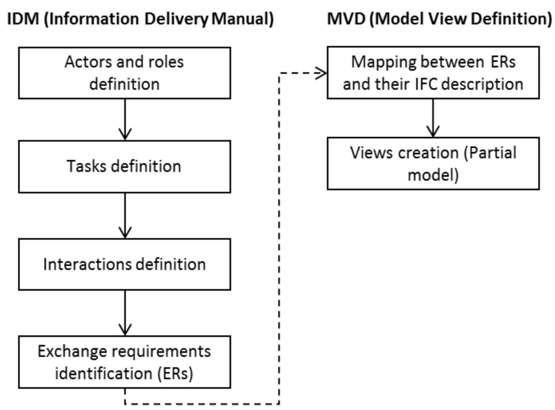


*Figure 2 IDM/MVD Methodology*

After assessing the possible and required enhancements of the IFC, an enriched MVD is defined. This MVD corresponds to what could be called a BSM (Building Simulation Model, see Figure 3). Then another requirement is to transform the IFC neutral model and to transform it into the internal data structure of the simulation engine.

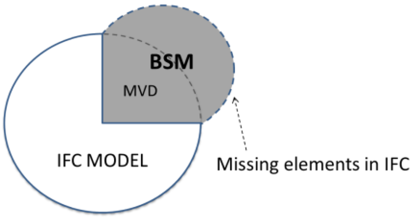


*Figure 3 Building Simulation Model*

In the following, we explain how we applied the IDM-MVD framework to create a BSM (Building Simulation Model) and describe the information flow between BIM and simulation.

**Design approach**

Step 1: Process map

The first step consists on the definition of the involved actor and their different tasks for the establishment of the process map (Figure 4). The process map will describe the exchange scenario.

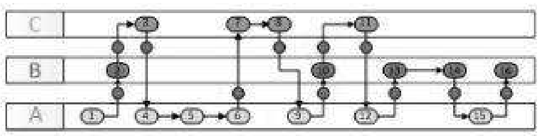


*Figure 4 The process map*

In our case actor A correspond to the design team, actor B to the client and actor C to the analysis team.

We focus on the exchange requirements that apply from the design to energy analysis. These exchange requirements will be passed on to the analysis team in order to evaluate the energy performance results. They will feature the information required to enable the exchange, allowing the mapping from design to analysis model.

Step 2: Model decomposition

Once the exchange requirement extracted, the second step consists in its decomposition (Table 1). The relevant data to be transferred to the simulation model must be extracted. In fact the model includes various data inputs that are relevant to building simulation:

-Building structure: includes the geometry of the building, space and energy-related requirements of the building.

-Energy-related equipment: describe material properties and HVAC systems

-Space related information: gives information about the building envelope.

-Site conditions: such as the building location, weather data and the surrounding area.

*Table 1*
*Exchange requirements BIM to energy analysis*

| Requirements | Description |
|---|---|
| **User Input** | **building structure, energy related equipment, space data, site data** |
| **Building structure** | spaces (geometry, space quantities, thermal requirements, lighting requirements, air quality requirements), space occupancy and usage, technical equipment, opaque components and transparent components, |
| **Energy related equipment** | mechanical ventilation, heating system, hot water system, cooling system, lighting system, photovoltaic system |
| **Space related** | building envelope |
| **Site** | building location, weather data, surrounding area, solar radiation |

This example describes the subsection of the developed Exchange Requirement table for Space element (Table 2). It decomposes information needed for the exchange.

*Table 2*
*Extract from the exchange requirement table*

| Type of info. | Info. needed | Req | Ospt | Type | Unit |
|---|---|---|---|---|---|
| Space | Name | | × | String | n/a |
| | Usage | × | | String | n/a |
| | Nb_housing | × | | String | n/a |
| | Height | × | | Real | M |
| | Zone_Height | × | | Real | M |

Step 3: Model mapping

We notice that IFC models contain the physical geometry of building elements in detail, but energy analysis requires an analytical geometric representation, which is expressed in a reduced and more simplified data set. Therefore, the extracted geometry has to be transformed from the physical representation to the analytical representation before being transferred to COMETH.

The approach to transform the geometry is carefully defined and focuses on geometry extraction from IFC model, and mapping to the simulation model. At this level, there is an extension of the exchange requirement table by adding the correspondent IFC element to each required information item.

Step 4: identification of missing elements

We first focus on possible IFC enrichments for to perform analysis with a simulation engine and apply the IDM (Information Delivery Manuals) /MVD

(Model View Definition) guidelines to select relevant IFC elements and to identify the missing ones, as compared to the simulation engine input data.
The identification of the missing elements leads us to the enrichment of Step 3. Indeed, apart the possibility of a direct mapping or a transformation, we can add additional information in the model.
This requires the establishment and the use of different mapping rules. (Cao et al., 2014) and (Wimmer et al., 2014) present different kinds of mappings rules from SimModel to Modelica, such as : One to One/ Many to One/ One to Many mappings , Gap, Transformation and Combination.

## PROCEDURE FOR IMPLEMENTATION

In this paper, we raise the question of developing a mechanism for mapping IFC specific concepts and proprietary data structure from the target application. The prototype tool is developed using C++.
The following activity diagram (Figure 5) is describing the whole process of the application. We can divide it into five main phases:

- Phase 1: BSM implementation
- Phase 2: Development of the mapping between BIMmodel and BSM
- Phase 3: Development of the mapping between BSMmodel and COMETHModel
- Phase 4: Export to XML
- Phase 5: Energy calculation

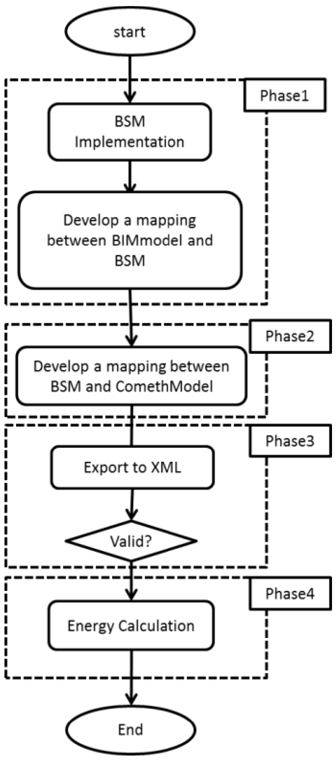


*Figure 5 General process -Activity Diagram*

**Phase 1: BSM implementation and the mapping between BIM and BSM**

The result of the application of IDM methodology was an MVD describing a subset of the IFC model that we need to exchange to perform energy analysis. In addition, we extracted some missing elements we need to add to our model. After the enrichment of the MVD, we will obtain and enhanced MVD, this is what we called BSM.
Our BSM can be described as a list of C++ objects materializing our MVD. We developed a mapping from our IFC model elements to BSMmodel object instances (Figure 6 illustrates an example of a mapping rule between an IFCbuilding entity and a BSMbuilding).

```
void BuilderBuilding::mappingRules()
{
    // set the name of the building
    std::wstring ws(this->o_ifc_building->getName());
    this->o_bsm_building->setName(std::string(ws.begin(), ws.end()));

    // set the index of the building
    std::wstring ws(this->o_ifc_building->getLongName());
    this->o_bsm_building->setIndex(std::string(ws.begin(), ws.end()));

    // set the description of the description
    std::wstring ws(this->o_ifc_building->getDescription());
    this->o_bsm_building->setComment(std::string(ws.begin(), ws.end()));
}
```

*Figure 6 BIM to BSM mapping*

**Phase 2: Mapping BSM to COMETH model**

This is a simplified extract of COMETH class diagram. As we can see, a project is composed by buildings (Building), and a building has interior partitions in thermal Zones (ThermalZone). A thermal zone is consisting of a group which is defined by the usage of the building. The group is composed by Openings (Baie), Opaques surfaces (Paroi), linear elements… This is how COMETH model is structured (Figure 7).

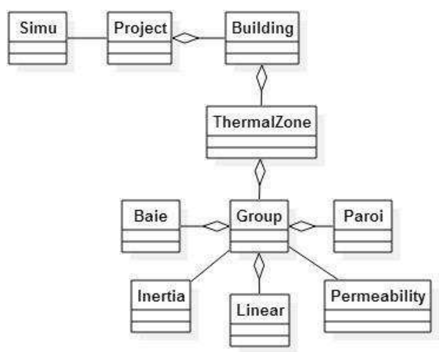


*Figure 7 COMETH Simplified class diagram*

It is important to admit that there is a big difference between the initial building model (geometry model) and the building model needed as input for energy simulation.

For example, one of the differences is that architectural spaces are not interpreted the same way. In COMETH the division of the architectural spaces is based on the usage of the area then on the thermal perspective (if they have the same thermal characteristics or not)

In addition to that, every energy simulation tool needs specific simulation parameters, for example in COMETH where we need to introduce the simulation mode, the location, the season and altitude. These parameters influence the numerical behavior of the simulation engine.

***Mapping rules***

In our case, we used three kinds of rules (Figure 8):

- Direct mapping: it consists on data translation between BSMmodel and COMETHmodel components or parameters. For example, BSMbuilding and COMETHbuilding having almost the same characteristics.
- Calculation: calculates new values from two or more elements from BSMmodel. For example, multiple walls in BSMmodel can be reduced to a single wall in COMETH.
- Addition of external data: adding missing data required for COMETH in the BSMmodel such as solar transmittance.

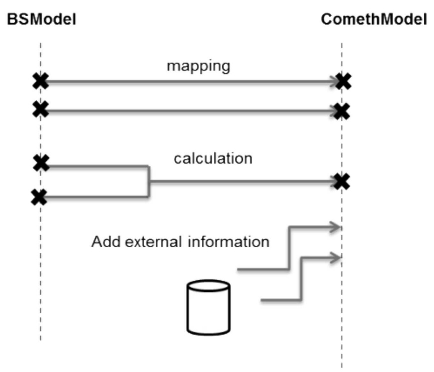


*Figure 8 Mapping Rules*

**Phase 3: Export to XML and energy calculation**

The input data format in COMETH is XML. This means that we had to translate our model into XML. At this level, the approach was to import the generated XML file into COMETH and perform analysis in passive simulation mode.

## CASE STUDY DESCRIPTION

In order to illustrate the relationship between design and energy analysis models, a case study is implemented, that relies on passive demonstration-focuses, INCA house and COMETH as a simulation engine.

We remind that the objective of this study is the interconnection between the design model described by IFC and the simulation model corresponding to COMETH simulation engine.

The IFC model in use describes an INCA house (Figure 9). The evaluated building is a single story building with three internal doors, one external door, multiple windows on each wall, a slab foundation and a roof.

We position ourselves in a Passive mode; this means that we will not take into account the HVAC systems in this study, but only the design of the building and its thermal requirements.

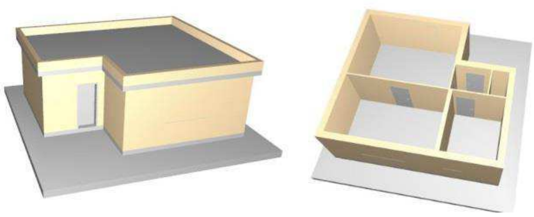

*Figure 9 INCA house*

We used as a case study, a house with 5 spaces. As a thermal zone is defined by usage, it will correspond to one single Zone in COMETH (same usage). And a group is characterized by the same thermal characteristics (Figure 10). Please note that, COMETH, takes into account only the exterior envelope of the building (external door and windows).

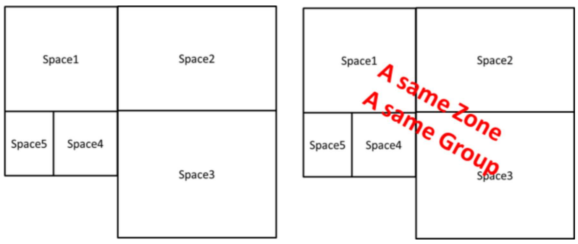


*Figure 10 COMETH interpretation of the INCA House*

## RESULTS AND DISCUSSION

This study shows that BIM model and energy model are not that compatible and, our work aims to propose a tool for a mapping between the initial design model and the simulation model based on COMETH.

In our work we followed the IDM process to structure the data exchange and draw the exchange requirements. As a result, we obtained a subset of the IFC model representing a simulation view. Further enhancements are still needed in order to generate an IFC file ready for energy simulation, that we call the Building Simulation Model (BSM).

Another contribution of this work is the mapping between the BSMmodel and the targeted simulation Model.

The work is still a preliminary result that presents some limitations in real practice. First, this work is only valid with COMETH simulation engine and we have to develop a more generic mapping/transformation module to include other simulation tools. Then, the work is taking into account only the simulation in a passive mode and does not include the whole HVAC system parameters for the moment. Finally, a future goal is to automate the mapping process in order to obtain a dynamic mapping between the two models.

## CONCLUSION

BIM interoperability and exchange format are still in their early infancy. We implemented a BIM-based solution for simulation enabling interdisciplinary exchange between design and energy model using COMETH simulation engine.

This work showed that the current version IFC4 still present limitations for a proper energy simulation that lead us to add some enhancements to the IFC model in order to express all the data needed to do simulation.

In this work, we followed a data modelling approach IDM-MVD and we got a view of the IFC model describing the exchange requirements from design phase to energy analysis.

We based the developed prototype on the obtained MVD; it was a big help to implement a mapping between the two models.

This application is only considering COMETH simulation engine, we would like to apply the approach proposed in this paper to other energy simulation tools and thus propose a more generic BSMmodel.

A first release of this work is based on a simple use case of a house in passive mode without considering the HVAC components. Therefore, we plan to consider them in a future work. In addition, as this prototype is only considering a simple use case, we intend to do tests on more complex buildings. This will help us to improve our tool and get closer to real-world projects.

## ACKNOWLEDGEMENT

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## REFERENCES

Attia, S. (2011). State of the art of existing early design simulation tools for net zero energy buildings: A comparison of ten tools. Technical report.

Bavastro, D., Capozzoli, A., Corrado, V., Giudice, M. D., Osello, A., Rietto, L., and Vigliani, E. 2014. From the architectural model to the energymodel: The use of BIM for the evaluation of the energy performance of buildings. Proceedings of Building Simulation 2013: 13th Conference of International Building Performance Simulation Association, Chambéry, France.

Bazjanac, V. and Maile, T. 2004. IFC HVAC interface to EnergyPlus - A case of expanded interoperability for energy simulation. SimBuild 2004, Boulder, CO.

Bazjanac, V. 2007. Impact of the U.S. National Building Information Model Standard (NBIMS) on Building Energy Performance Simulation, Proceedings of Building Simulation 2007, Bejing, China.

BLIS Project. 2009. IFC solutions factory the model view definition, website http://www.blis-project.org/IAI-MVD/.

Cao, J., Maile, T., O'Donnell, J., Wimmer, R., van Treeck, C. 2014. Model Transformation from SimModel to Modelica for Building Energy Performance Simulation, BauSIM2014, Aachen, Germany.

Cemesova, A., Hopfe, C., and Rezgui, Y. 2012. PassivBIM– a new approach for low energy simulation using BIM, eWork and eBusiness in Architecture, Engineering and Construction: ECPPM 2012, Reykjavik, Iceland.

EBC Annex 60 Project. 2012-2017. IEA EBC Annex 60, website http://www.iea-annex60.org.

El Asmi, E., Robert, S., Mazza, D., and Zreik, K. 2014. Multi-physical model simulation and interoperability through BIM/ IFC using COMETH simulation engine, Architecture, City & Information Design, Nice, France.

Haas, B. and Corrales, P. 2013. Solution pour l'interopérabilité avec COMETH, Proceedings of Building Simulation 2013: 13th Conference of International Building Performance Simulation Association, Chambéry, France.

Hitchcock, R. J. and Wong, J. 2011. Transforming IFC architectural view BIMs for energy simulation, Proceedings of Building Simulation 2011: 12th Conference of International Building Performance Simulation Association, Sydney, Australia.

Jeong, W., Kim, J. B., Clayton, M. J., Haberl, J. S., and Yan, W. 2014. Translating building information modeling to building energy modeling using model view definition, The Scientific World Journal, vol. 2014, Article ID 638276, 21 pages.

Kim, J. B., Jeong, W., Clayton, M. J., Haberl, J. S., and Yan, W. 2015. Developing a physical BIM library for building thermal energy simulation. Automation In Construction, 50:16–28.

Laine, T., Hanninen, R. and Karola, A. 2007. Benefits of BIM in the Thermal Performance

Management, Proceedings of Building Simulation 2007, Bejing, China.

Maile, T., Fischer, M., and Bazjanac, V. 2007. Building energy performance simulation tools - a life-cycle and interoperable perspective. Technical report, CIFE - Center for Integrated Facility Engineering.

Moon, H. J., Choi, M. S., Kim, S. K., and Ryu, S. H. 2011. Case studies for the evaluation of interoperability between a BIM based architectural model and building performance, Proceedings of Building Simulation 2011: 12th Conference of International Building Performance Simulation Association, Sydney, Australia.

O'Donnell, J., See, R., Rose, C., Maile, T., Bazjanac, V., and Haves, P. 2011. Simmodel: A domain data model for whole building energy simulation, Proceedings of Building Simulation 2011: 12th Conference of International Building Performance Simulation Association, Sydney, Australia.

O'Donnell, J. T., Maile, T., Rose, C., Mrazovic, N., Morrissey, E., Regnier, C., Parrish, K., and Bazjanac, V. 2013. Transforming BIM to BEM: Generation of building geometry for the NASA Ames sustainability base BIM, Technical report, Berkley Lab.

Open Geospatial Consortium Inc. 2008. Aecoo-1 testbed Information Delivery Manual (IDM) for building performance and energy analysis (BPEA) thread, Technical report, buildingSMART alliance.

O'Sullivan, B. and Keane, M. 2005. Specification of an IFC based intelligent graphical user interface to support Building Energy Simulation, Proceedings of Building Simulation 2005, Montreal, Canada.

Robert, S., Mazza, D., Hilaire, B., Sette, P., and Vinot, B. 2014. An approach to enhancing the connection between bim models and building energy simulation – HVAC systems in the loop, eWork and eBusiness in Architecture, Engineering and Construction ECPPM 2014, Vienna, Austria.

Rose, M. and Bazjanac, V. 2013. An algorithm to generate space boundaries for building energy simulation, Engineering with Computers, 31(2):271–280.

U.S. Department of Energy (US-DOE), U. D. 2004. Energyplus Energy simulation software. http://www.eere.energy.gov/buildings/energyplus.

Van Treeck, C., Rank, E. 2007. Dimentional reduction of 3D building models using graph theory and its application in building energy simulation, Engineering with Computers, 23, 109-122.

Wimmer, R., Maile, T., O'Donnell, J., Cao, J., van Treeck, C. 2014. Data-Requirements Specification to Support BIM-based HVAC Definitions in Modelica, BauSIM2014, Aachen, Germany.

Wurtz, F. 2013. Présentation de la participation Française, http://ibpsa.fr/jdownloads/Conferences_et_Congres/IBPSA_France/2013_journeeIBPSA/01-FWurtz/journeebatnoeudenergetiquefwurtzv14.pdf.

Yan, W., Clayton, M., Haberl, J., Jeong, W., Kim, J. B., Kota, S., Alcoce, J. L. B., and Dixit, M. 2013. Interfacing bim with building thermal and daylighting modelling, Proceedings of Building Simulation 2013: 13th Conference of International Building Performance Simulation Association, Chambéry, France.