## Process Map

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| ***Name*** | **EnEff:BIM** |

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| **Identifier** | Overall process EnEff:BIM |

| **Change Log** | | |
|---|---|---|
| 2016-08-30 | First draft | wimmer@e3d.rwth-aachen.de |
| 2016-09-19 | Adding content | sergio.pinheiro@ucdconnect.ie |
| 2016-09-21 | Adding content | wimmer@e3d.rwth-aachen.de |
| 2016-09-22 | Adding energy relevant German standards and Guidelines | wimmer@e3d.rwth-aachen.de |
| 2016-09-22 | Adding international standards and guidelines | sergio.pinheiro@ucdconnect.ie |
| 2016-11-17 | Editing content | james.odonnell@ucd.ie |

### *Overview*

The EnEff-BIM project represents the Activity 1.3 of IEA EBC Annex 60. This work is conducted within the German research project EnEff-BIM - Energy Efficient Modelling and Simulation Based on Building Information Modelling (BIM), which is funded by the German Federal Ministry for Economic Affairs and Energy (BMWi) under Contract No. 03ET1177A-F. The research focuses on the generation of objected-oriented Modelica simulation models based on the automated reuse of data from BIM. By doing so, this activity aims to address the issues related to the tedious, cumbersome and error-prone processes of manual data conversion and model generation. The tool-chain provides interfaces to open BIM standards such as the ISO 16739:2013 (Industry Foundation Classes – IFC) and a modularly structured framework that allows for further and distributed developments on an open source basis by an international community. In the context of energy codes, we refer to the German Energy code (EnEv) and the US Energy code (ASHRAE 90.1) as the main basis for energy simulation.

The purpose of this Process Map is to illustrate the developed semi-automated model transformation tool-chain between BIM and Modelica (refer to the annex 60 final report for more information).

Three actors are involved in the transformation process: 1) the architect generates a geometry model, verifies model correctness and generates 2$^{nd}$ level space boundaries, a requirement for heat transfer surfaces within typical energy simulation tools; 2) the HVAC engineer uses this geometry model and the first draft of the HVAC systems as a starting point, and subsequently optimises the HVAC model of the building in preparation for Building Energy Performance Simulation (BEPS) tools. The HVAC engineer also performs a validation check on the system configurations and 3) the simulation team gather the remaining necessary data to enrich the simulation model, run the BEPS and analyse the results.

#### Scope

The scope of this process map is to enable consultation of a simulation team for the development of an energy efficient HVAC concept for a building. This step usually takes place during the design stage of the building, after the first draft of the building is confirmed by the Architect and HVAC Engineer.

#### General Description

In order to carry out a building energy performance simulation analysis, the energy simulation team need to collect building information from different sources. At the same time, this team needs to transform the information into required inputs for the energy simulation software and in doing so, add any missing information to enable simulation execution. The Process Map presented here defines the information exchange requirements for advanced building energy performance simulations tools, in this case Modelica. These exchange requirements are essential for realizing data exchange between BIM and BEPS tools. Such powerful predictive tools enable investigation and informed decision making with respect to environmental and energy performance of different design and retrofit design alternatives. Results from simulated models provide designers with the necessary information to deliver optimal thermal comfort and minimised energy consumption predictions.

The Process Map also describes the stakeholders and the role of these stakeholders in the exchange process, illustrating what information is being exchanged, which actor needs the information extracted and at which point in the process this information is needed.

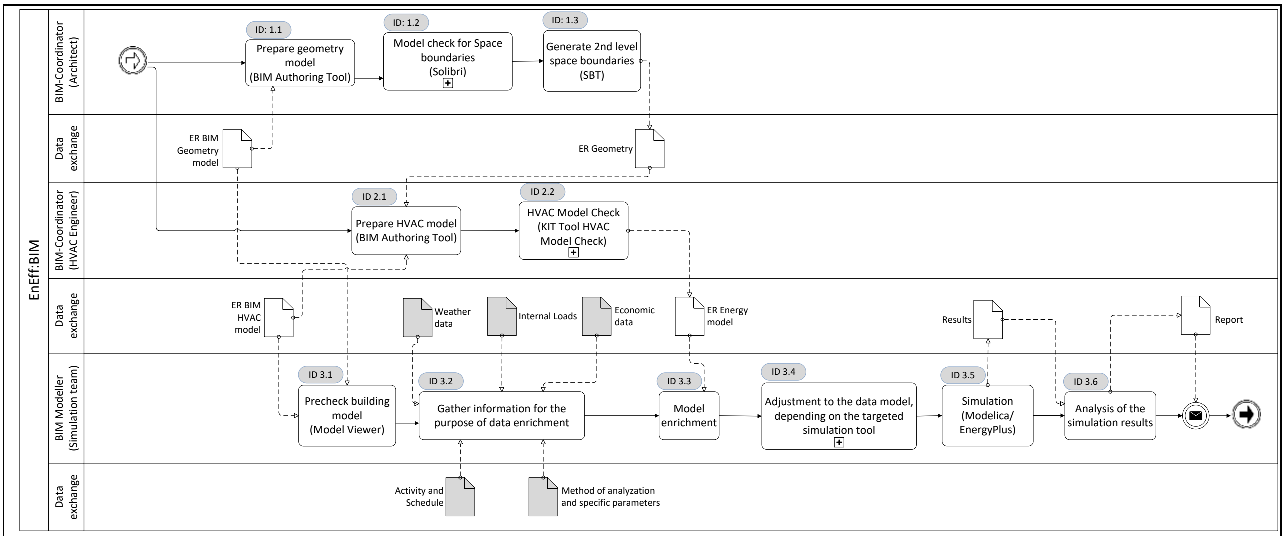
According to Maile et al. (2007), the information needed to conduct a simulation is usually the following:
- Building structure: Geometry, spaces and thermal zones, building orientation and construction, building usage;
- HVAC systems: Heating, lighting, ventilation and air conditioning systems;
- Internal loads: Schedules for lighting, equipment and people;
- Weather data and other simulation specific parameters.

The output results of the energy analysis may cover:
- Assessment of the HVAC system's energy performance for compliance with regulations and energy targets;
- Flexible and fast modelling of building energy and control systems to accelerate innovation leading to cost-effective and very low energy systems for new and existing buildings;
- Rapid prototyping of new or existent building systems;
- Analysis of the operation of building systems;
- Development, specification, verification and deployment of building controls, and
- Reuse of models during operation for functional testing, for verification of control sequences, for energy-minimising controls, fault detection and diagnostics.

## *Specification of Processes*

*Overall process map*

## Process Map: EnEff:BIM overall process map




### LANE: BIM-Coordinator (Architect)

**Preparing geometry model (BIM Authoring Tool) [ID:1.1]**

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| Type | Task |
| Name | Prepare geometry model (BIM authoring tool) |
| Documentation | Building Energy Performance Simulations (BEPS) tools require building geometry in a simplistic |

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| | representation when compared with typical BIM based CAD tools. As a result, building geometry representations must be prepared, i.e. simplified, reduced, translated or interpreted, prior to use in BEPS tools (Bazjanac and Kiviniemi 2007).<br><br>The first step in the tool-chain prepares the BIM for generation of 2$^{nd}$ level space boundaries, and this process uses the work prepared by Bazjanac (2010). This step considers that space types are assigned within the model and that these types contain the relevant properties as required by BEPS, all of which is in accordance with German standard DIN V 18599-10 (2013). Once geometry, construction types and space types are finalized, the BIM is ready for validation, a necessary quality control process prior to energy analysis. As such, the validation process exports BIM from the CAD application to IFC format and evaluates the model using a model validation tool, e.g. Solibri Model Checker, to ensure the BIM is complete and fit for BEPS modeling purposes, as defined by O'Donnell et al. (2013). |

**Model check for space boundaries (Solibri)** [ID:1.2]

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| Type | Task | |
| Name | Model check for space boundaries (Solibri) | |
| Documentation | This step checks if the BIM contains 2$^{nd}$ level space boundaries. Space boundaries are defined as system of surfaces that delineates walls, slabs, roofs, columns, beams, windows and doors. Such space boundaries are critical part of the building geometry representation and are necessary for BEPS. In cases where space boundaries are missing, Space Boundary Tool can be used to create the required 2$^{nd}$ level space boundaries and add them to the BIM. | |

**Create 2$^{nd}$ level space boundaries (SBT)** [ID:1.3]

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| Type | Task type | |
| Name | Create 2nd level space boundaries (SBT) | |
| Documentation | At this point, 'Space Boundary Tool' (SBT) imports the BIM and checks for the presence of required 2$^{nd}$ level space boundaries. If these boundaries are missing, SBT will generate the appropriate boundary instances (Rose 2013). With the 2$^{nd}$ level space boundaries in place, SBT also converts the IFC BIM into the input format required by BEPS tools (SBT-1, 2016). | |

## *Specification of Data Objects*

## Exchange Requirement Data Objects

### ER BIM Geometry Model

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| Type | Data Object |
| Name | ER BIM Geometry Model |
| Documentation | The BIM geometry provides initial information about building design for the architect and the simulation team. The information exported in IFC4 format relies on the data exchange requirements defined in the Model View Definition (MVD), which this project developed to specify the specific requirements (e.g. geometry, construction, usage, locations, space boundaries, etc.) needed by BEPS tools. This MVD also filters the information that is not relevant for BEPS, thus providing a clean and robust file. IFC file export in accordance with the corresponding MVD represents the first validation of the IFC file. This file validation checks if relevant properties, semantics and entities are present and correctly modeled.<br><br>Two assumptions are now required: 1) the architect has, at this point in the process, defined the whole building concept design, including all the building elements, space objects, and 2) that the IFC4 data model is exported from the CAD tool.<br>The geometry model should include the following elements and in the following hierarchical order:<br>- Site<br>- Building<br>- Building stories<br>- Spaces |

**ER Geometry**

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| Type | Data Object |
| Name | ER Geometry |
| Documentation | This exchange is the first information received by the HVAC engineer from the Architect in this process. The HVAC engineer receives the model with 2nd level space boundaries and thermal zones which have been defined in accordance with DIN V 18599-10. A thermal zone is a single space or group of spaces that have homogeneous thermal load and conditioning requirements. Thermal zoning is relevant for the engineer to determine the number, dimension and type of HVAC systems required. Thus, the engineer is able to finalize the design of the HVAC systems. |

**LANE: BIM-Coordinator (HVAC-Engineer)**

**Prepare HVAC model (BIM authoring tool)** [ID: 2.1]

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| Type | Task | |
| Name | Prepare HVAC model (BIM authoring tool) | |
| Documentation | At this stage, the HVAC Engineer receives the validated IFC file containing 2nd level space boundaries and thermal zones together with the earlier stage draft of the BIM HVAC model. Information including location, orientation, wall constructions, space types and 2nd level space boundaries are relevant input data for the definition of the thermal zones. After all the relevant information for decision making are considered, the HVAC engineer finalizes the design of the HVAC systems. In this step the engineer uses static and/or conservative dimension methods, like heating/cooling load (DIN EN 12831 (2003), VDI 2078 (2015)), pipeline design, dimensioning and pipework network calculation and measures to account for seasonal variations in thermal loads.<br>The MVD includes modeling specifics for the building envelope and accounts for the definition of each respective material and material layer and is done so in accordance with German guideline VDI 6007 (2012). Complex objects such as windows or doors are modeled using the concept 'Material Constituent', which allows a comprehensive definition of an object's materials. The definition of the walls, ceilings and floors is done in layers. Relevant data are:<br>- Mass density [kg/m³]<br>- Thermal conductivity [W/m K]<br>- Specific heat capacity [J/kg K]<br>- Thickness of the layers [m]<br>- Solar reflection index [-]<br>- Coefficient of heat transfer [W/m² K]<br>- Emissivity [-]<br>- Absorption coefficient [-]<br>- …<br>Thermal zones are further defined using the IFC grouping mechanism 'IfcZone'. The definition of the thermal zones, and respective spaces, adheres to the data of the following IFC property sets:<br>- PSet_SpaceOccupantRequirements<br>- PSet_SpaceThermalRequirements<br>- PSet_SpaceThermalDesign<br>- PSet_SpaceThermalLoad<br>- PSet_ThermalLoadDesignCriteria<br>- PSim_space<br>- …<br>The MVD also includes details additional physical and operational properties that are relevant for BEPS modeling of HVAC components. With this information available to the HVAC engineer, initial sizing calculations are performed (externally to the BEPS tool) and the first valid draft of the HVAC system for BEPS is created. The HVAC engineer merges this draft representation of the HVAC system with the architect's model to design the breakthroughs according to the zoning for fire purposes. | |

**HVAC model check (KIT tool HVAC model check)** [ID: 2.2]

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| Type | Task | |
| Name | HVAC model check (KIT tool HVAC model check) | |
| Documentation | Quality assurance of the BIM is an important precondition for a qualified BEPS process. Thus, it is necessary to have a coherency check of the IFC data to ensure compliance with overall tool-chain quality requirements. This requires specifically defined rules for 1) model quality and 2) IFC model content. For example, verify a HVAC system topology where all pipes within a piping circuit must be correctly defined, connected and referenced. This step uses the KIT tool 'HVAC model check' to ensure desired model quality. In cases where model quality is inadequate, a modification needs to be authorized by the responsible actor, for example the architect, engineers and/or client. After a successful model check, the model passes to the simulation team where, the information defined in the IFC data model is transformed into SimModel format, which is a specifically define BIM for BEPS. The simulation team also adds further BEPS relevant data in order to complete the model prior to BEPS execution. | |

## Exchange Requirement Data Objects

**ER BIM HVAC model**

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| Type | Data Object |
| Name | ER BIM HVAC model |
| Documentation | The BIM HVAC model contains the HVAC systems as designed in an earlier stage of the project. In the same manner as BIM geometry, the information contained in the HVAC model should correspond to the information exchange requirements defined in the MVD (e.g. HVAC components, distribution system, etc.). The HVAC engineer uses this information to finalize system design. |

**ER Energy model**

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| Type | Data Object |
| Name | ER BEPS model |
| Documentation | The BEPS model contains the first valid draft of the HVAC systems and the geometry with $2^{nd}$ level space boundaries. This model serves as basis for the simulation team to carry out dynamic simulations using a particular BEPS tool.<br>This BEPS model contains all the information generated by conventional, well-established and standardized load calculation procedures. Typically, the energy demand required to satisfy thermal comfort is calculated using heating and/or cooling loads. These loads are in turn used for HVAC system sizing where these load represents the extreme thermal conditions that the building will encounter, conditions referred to as heating and cooling design days in the HVAC industry. Additional results from calculations including pipework dimensions, pipework network calculations and the need for summer heat protection calculation are also contained within the BEPS model. |

**LANE: BIM Modeler (simulation team)**

**Precheck building model (model viewer)** [ID:3.1]

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| Type | Task | |
| Name | Precheck building model (model viewer) | |
| Documentation | The simulation team receives the combined geometry and HVAC model according to the information exchange requirements defined in the MVD. In this case, the MVD defines a subset of the IFC data model that is needed to support the target BEPS tools. Adhering to this specific MVD enables generation of reliable and consistent IFC models which capture all the relevant information to carry out a BEPS simulation. | |

**Gather information for the purpose of data enrichment** [ID:3.2]

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| Type | Task | |
| Name | Gather information for the purpose of data enrichment | |
| Documentation | The specific BEPS objective determines the information relevant to a given BEPS task. Several | |

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| | components of information are required and include:<br>- Weather data<br>- Internal loads<br>- Economic data<br>- Activity and schedule<br>- Specific parameters for the simulation tool<br>The information is typically available from existing libraries with additional information provided by the client or gathered from external sources. |

**Model enrichment** [ID:3.3]

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| Type | Task | |
| Name | Model enrichment | |
| Documentation | At this point all the information necessary to run a BEPS is collected from all different sources. The model is prepared and will contain the relevant information in accordance with the target BEPS tool. | |

**Adjust data model, depending on the targeted simulation tool** [ID:3.4]

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|---|---|---|
| Type | Task | |
| Name | Adjust data model, depending on the targeted simulation tool | |
| Documentation | Model adjustments specific to a particular tool are relevant at this point in the process. As a result the simulation team insert specific parameters into the data model and these data are stored in an appropriate manner. | |

**Simulation (Modelica/EnergyPlus)** [ID:3.5]

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| Type | Task | |
| Name | Simulation (Modelica/ EnergyPlus) | |
| Documentation | The simulation team will use the appropriate BEPS tool in accordance with the enriched data model. This tool can be either EnergyPlus or Modelica tool (e.g. Dymola, SimulationX, OpenModelica). | |

**Analysis of the simulation results** [ID:3.6]

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| Type | Task | |
| Name | Analysis of the simulation results | |
| Documentation | At this point the results may be evaluated directly from the BEPS output. Regardless of the chosen method, the results are compared to the project's energy targets. If the targets are not achieved, then the BIM-Coordinator must go back to Task ID 1.1 and create design alternatives, which can include modifications to building geometry, constructions, HVAC systems or other objects. If the targets are achieved, the simulation team can approve the design of the building. | |

## Library Data Objects

**Weather Data**

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|---|---|
| Type | Data Object |
| Name | Weather Data |
| Documentation | Weather files provides statistically averaged climate data for a given location. The source format for these files varies and can include (Crawley, 1998):<br>- Typical Meteorological Year (TMY, TMY2, TMY3)<br>- Weather Year for Energy Calculations (WYEC2)<br>- International Weather for Energy Calculations (IWEC)<br>- Test Reference Year (TRY)<br>Some of the information that these files include is the following:<br>- Cloud coverage<br>- Wind direction (East/North/West/South)/ speed (m/s))<br>- Air temperature<br>- Atmospheric pressure<br>- Water vapor content |

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| | - Relative/ absolute humidity<br>- Direct/ diffuse solar radiation strength<br>- … |

**Internal Loads**

| Type | Data Object |
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| Name | Internal Loads |
| Documentation | Internal loads are any sensible and latent heat emitted within an internal space from any source that contribute to the heat and mass balance in that space. The following sources are considered in most cases:<br>- Occupancy: defines the number of people in the space and the activity level for these people. Metabolic rate is a key input that impacts sensible and latent heat gain per person under the design conditions.<br>- Lighting: defines the sensible loads produced by artificial lighting. When defining the total internal heat gain, the following parameters are required: total electrical input power (W), fraction of input that enters the space as conduction, convection and radiation.<br>- Office equipment and computers: personal and office equipment results in heat gains to the space equal to the total power input (W). The internal gains from equipment can be estimated from basic manufacture data and fraction of input that enters the space as conduction, convection and radiation must also be defined. |

**Economic Data**

| Type | Data Object |
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| Name | Economic Data |
| Documentation | If economic data besides the energy target values is in the client's interest, it should be checked whether the targeted BEPS tool library is able to facilitate this functionality or not. |

**Activity and schedule**

| Type | Data Object |
|---|---|
| Name | Activity and schedule |
| Documentation | Typically, schedules for BEPS follow a regular pattern, mostly daily, weekly and seasonal patterns are used. The schedules are assigned to the activity:<br>- Occupants: Desk work/ Standing work (presenting, cleaning)<br>- Equipment: Computers/ printers/ …<br>- Lights: Desk light/ room lights/ … |

**Specific parameters for the simulation tool**

| Type | Data Object |
|---|---|
| Name | Specific parameters for the simulation tool |
| Documentation | Select the BEPS tool (EnergyPlus/ Modelica) for analysis where the tool must execute given the data available for a given project.<br>Examples of specific data are the time steps for the simulation, the definition of the used medium, physical component parameters, start values or definition of output requests. |

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