Process model for BIM-based MEP design

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Abstract. Planning quality is a key aspect for the development of sustainable buildings. This particularly applies to mechanical, electrical and plumbing (MEP) systems, which have a high impact on the building performance. The design of these systems considerably affects construction and operational costs. Moreover, it has a substantial impact on the consumption of resources such as energy or water and also on the building quality in terms of user satisfaction. Building information modeling (BIM) is a method capable of substantially improving the quality of MEP design. This requires adequate component models as well as processes describing the proper use of these models in a BIM project. This paper presents a Business Process Model and Notation (BPMN) model which describes the required interactions between project stakeholders during the design phase of a geothermal heat pump system. It describes the roles, tasks and responsibilities of the involved stakeholders and outlines which kind of information is required from whom at which point of time. The specific activities of the stakeholders are linked by information flows. In addition to the process model, a set of parameters describing a heat pump is presented. The parameters can be used as attributes in a BIM model. Each parameter is assigned to the design phase in which it is needed for the first time. This establishes a link between the attributes in the BIM model and the process model. Both, the process model and the parameter set were evaluated by MEP experts.

1. Introduction

The building sector has the highest final energy demand globally representing 31% of the total final energy consumption. Heating accounts for 75% of this energy consumption. The utilization of digital technologies has the potential to save up to 12% of energy for domestic hot water, heating and cooling until 2040 [1].

Building information modeling (BIM) is one of the most promising digital methods in the architecture, engineering and construction (AEC) industry [2]. Hartman et al. [3] pointed out that for a broad implementation of BIM two kinds of languages are required: one language to describe data models for BIM implementation and another one to describe the multidisciplinary BIM work processes [3]. Usually, many stakeholders are involved in the planning process of a construction project. Information management between these stakeholders across the various project phases is an important factor for successful BIM collaboration. A major challenge in project coordination is the question of responsibility for delivering data at the right time in the different project phases [4]. This is especially true for mechanical, electrical and plumbing (MEP) as this domain has many interfaces to other disciplines. One of the reasons why BIM has not yet fully been adopted is that there is a lack of well-defined process
models for BIM collaboration. Moreover, there is a need for practicable descriptions of project requirements and BIM components [6].

The objective of this paper is to provide a process model for the BIM-based design of a geothermal heat pump with a vertical closed-loop borehole heat exchanger (BHE). Heat pumps have become an important heating system in Europe with steadily increasing annual sales [7]. BPMN (Business process model and notation) is used to represent the process model in this paper. To facilitate the practical applicability of the process model, a data set with design parameters of a geothermal heat pump is presented. The parameters can be used as attributes in a BIM model of a heat pump. Each parameter is rated according to its importance in the design process and assigned to a design phase. Parameters ranked with a high degree of importance are presented and discussed in detail. The results can be used for setting up and managing BIM projects where a geothermal heat pump system is used as heating system for the building.

2. Methodology

The use of process models is a common way to describe the tasks, responsibilities and workflows in a BIM project. Integrated Definition for Function Modeling (IDEF) [8] [9] as well as BPMN [4] have been used to represent process models for BIM projects. International standards such as EN ISO 29481-1 propose BPMN for generating process diagrams for the development of information delivery manuals (IDMs) [10]. For this reason, BPMN has been chosen to describe the design process of a heat pump system in this paper. The presented process model should support the creation of IDMs or relevant BIM documents in case the building is equipped with a geothermal heat pump system. It should also help to manage and monitor the digital information flow between the project participants in the course of the development of the BIM model. This includes the development of rulesets for automatic BIM model checking.

The IFC4 Add2 (Industry Foundation Classes) data model defines a heat pump as unitary equipment (IfcUnitaryEquipment), which means that the heat pump model consists of models of the individual subcomponents of the heat pump (e.g., evaporator, compressor, throttle or condenser etc.). In practical MEP planning however, it is unusual to consider individual components of a heat pump. It is a common practice to handle a heat pump as a whole device. For this reason, characteristic parameters of a heat pump were collected in order to create the basis for a heat pump data model on device level. The collected parameters were subsequently assigned to different design stages and evaluated by four MEP experts each on having more than 10 years of practical experience. The presented heat pump parameters can be used to set up custom heat pump models in BIM authoring software. It may also be used as a basis for an alternative heat pump model in IFC or to extend the current IFC4 Add2 model with parameters which are not yet implemented.

3. Results

The results are presented in two parts. First, the workflow and data exchange through three design stages of geothermal heat pump planning are illustrated by means of a BPMN process model. In the second part, collected heat pump parameters are presented and categorized, including a rating of their importance in different design stages.

3.1. BPMN model of the BIM-based design of geothermal heat pumps

Figure 1 shows the workflow and information flow during the design process of a geothermal heat pump with a vertical closed-loop BHE using BPMN (based on the ISO 22263 standard [11]). It shows the interactions of project participants from six disciplines: architecture, heating, ventilation and air-conditioning (HVAC), civil engineering, geotechnical engineering (GEO), electrical engineering and building automation (BA).
At the beginning of the outline conceptual design phase, the architectural model and the requirements of the client and facility managers are analyzed by the HVAC engineer. Based on these requirements and a preliminary heat and cooling load calculation the basic operating conditions of the heating system are specified and main parameters of the heat pump system such as the required heat output, the electric load, dimensions, weight etc. are estimated. The refrigerant type and the basic system configuration are chosen. In large scale projects, the geotechnical engineer plays an important role in the course of system selection: The results of the thermal response test indicate whether the geothermal conductivity of the soil is sufficient or not to provide the required heat output. At the end of the outline conceptual design phase, the architect gets a technical concept of the heat pump system and requirements concerning the space needed for the technical equipment in the building and for the BHE in the surrounding area.

In the full conceptual design stage the parameters specified in the previous stage are extended and refined. The capacity of the heat pump is determined based on a detailed heating and cooling load calculation. This allows for a more precise specification of the dimensions and technical parameters of the heat pump. The results are required for the subsequent building permission process. In the coordinated design phase, the design and layout of the heat pump system is refined and completed and documents for the bidding and negotiation process are prepared. Engineers from all domains should be integrated into the design process as early as possible as shown in the process model.
3.2. Data set of design relevant parameters for geothermal heat pumps

Data was collected from different sources such as national and international standards (e.g., [12]), product data sheets and data schemes such as IFC4 Add 2 in order to compile the following parameter set for a geothermal (brine-to-water) heat pump as described in [13]. Overall, 76 parameters relevant to the design phase were identified. Figure 2 shows different categories to which the individual parameters were assigned.

Each parameter was subsequently assigned to the design phase, in which it is required for the first time. The initial assignment was done by four HVAC experts. In general, the assignments of the experts were in good agreement. In cases of differing opinions, parameters were assigned to the phase with the most entries. The parameters were finally assigned as follows: 30 to the outline conceptual design phase, 28 to the full conceptual design phase and 18 to the coordination design phase.

The four HVAC experts were also asked to rate the relative importance of each parameter. For this purpose, three importance categories (‘high’, ‘medium’ and ‘low’) were defined as outlined in table 1. The rating should help to establish a common sense between all project participants about the priority specific parameters should receive in the course of the development of the BIM model. Particularly for parameters rated with ‘high’ degree of importance, care must be taken to ensure that they are duly defined, fully incorporated in the digital building model and kept up to date throughout all project phases.

Figure 3 shows the distribution of the parameters according to their degree of importance in each design stage. It can be seen that the parameters with a ‘high’ degree of importance are predominant in the outline conceptual design phase. This result underlines the importance of early design stages in which requirements and the basic design-relevant parameters are specified. This is especially true for BIM projects as the establishment of BIM triggers a trend towards more detailed planning in early design stages.

| Category                                | Number of parameters | Outline conceptual design | Full conceptual design | Coordinated design |
|-----------------------------------------|----------------------|---------------------------|------------------------|--------------------|
| Thermal and efficiency parameters       | 10                   | 4                         | 2                      | 4                  |
| Electrical parameters                   | 9                    | 5                         | 3                      | 1                  |
| Geometry                                | 6                    | 6                         | 0                      | 0                  |
| Refrigerant                             | 6                    | 6                         | 0                      | 0                  |
| Operational parameters                  | 8                    | 3                         | 5                      | 0                  |
| Fluid mechanics                         | 14                   | 0                         | 14                     | 0                  |
| Cost                                    | 2                    | 1                         | 1                      | 0                  |
| Temperature range                       | 4                    | 4                         | 0                      | 0                  |
| Machine specific parameters             | 12                   | 1                         | 3                      | 8                  |
| Building automation                     | 5                    | 0                         | 0                      | 5                  |
| Sum of attributes                       | 76                   | 30                        | 28                     | 18                 |

Figure 2. Categorized parameters of a geothermal pump and distribution among different design stages.

Figure 3. Distribution of the degree of importance of parameters in each design stage.
Table 1. Categories for rating the degree of importance of the parameters.

| Importance category | Criteria                                                                                                                                                                                                                                                                                                                                 |
|---------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| High                | • Parameters to be defined together with the client in order to determine the basic requirements for the planning task.  
                        • Parameters that are required to fulfil the planning task and which are essential for the work progress of several of the involved project participants.  
                        • Parameters needed for the building permit and parameters that represent criteria required to assess technical equality in the tendering and award process.                                                                                          |
| Medium              | • Parameters that are required to fulfil the planning task and which are essential for the work progress of a specific project participant (e.g., parameters required by HVAC engineers to dimension a specific component).                                                                                                           |
| Low                 | • Parameters which are not required for common planning tasks but which may be required for optional or special tasks (e.g., additional or more detailed simulations, additional documentation etc.).                                                                                                           |

Table 2 summarizes all parameters rated as ‘high’. It also shows the design phases in which the parameters are relevant for the first time. The table reflects the opinion of the four HVAC experts consulted. The following examples illustrate the application of the criteria in Table 1.

The heat output and electrical power at specified operating conditions for example are important for estimating the size and capacity of the heat pump. The two parameters are classified ‘high’ as other important parameters depend on them. The geometric dimensions and the weight of the heat pump depend on the heat pump capacity. This information is required by the architect and the structural engineer (e.g., to determine the location and size of technical rooms). The refrigerant charge is another important parameter derived from the heat pump capacity as pointed out below. Estimating the coefficient of performance (COP) and the energy efficiency ratio (EER) at specified operating conditions is also essential in the outline conceptual design as the granting of subsidies often relies on these parameters. This has a significant impact on cost calculations, which, in turn, are an important basis for decision-making by the client.

Refrigerant parameters (refrigerant type and charge, toxicity, flammability) are highly important because they determine the required extent of safety measures as specified in the EN 378 standard [14]. This concerns for instance the installation site (e.g., permissibility of an indoor installation) or requirements to equip the technical room with additional systems (e.g., additional ventilation, fire protection systems etc.). The parameters thus have an impact on the floor plan and on the scope and configuration of MEP systems. As the refrigerant choice and the refrigerant charge are safety-critical parameters, they also play an important role in the building permit.

Parameters required to assess technical equality of products in the tendering and award process include the nominal heat output, cooling output, COP and EER, the sound power level, the refrigerant type and the refrigerant charge. This justifies the rating ‘high’ of these parameters.
Table 2. Geothermal heat pump parameters with a ‘high’ degree of importance.

| Category                          | Parameter                                                                 | Unit       | Outline conceptual design | Full conceptual design | Coordinated design |
|----------------------------------|---------------------------------------------------------------------------|------------|---------------------------|------------------------|--------------------|
| Thermal and efficiency parameters| Required heat output at specified operating conditions                   | kW         | •                         |                        |                    |
|                                  | Required Coefficient of Performance (COP) at specified operating conditions | (-)        | •                         |                        |                    |
|                                  | Required Energy Efficiency Ratio (EER) at specified operating conditions   | (-)        | •                         |                        |                    |
|                                  | Nominal heat output                                                       | (kW)       |                           | •                      |                    |
|                                  | Nominal cooling output                                                    | (kW)       |                           | •                      |                    |
|                                  | Nominal Coefficient of Performance (COP)                                  | (-)        | •                         |                        |                    |
|                                  | Nominal Energy Efficiency Ratio (EER)                                     | (-)        |                           | •                      |                    |
| Electrical parameters            | Required power at specified operating conditions                         | (kW)       | •                         |                        |                    |
|                                  | Starting current                                                          | (A)        |                           | •                      |                    |
|                                  | Connection voltage                                                        | (V)        |                           | •                      |                    |
|                                  | Nominal power                                                             | (kW)       |                           | •                      |                    |
| Geometry                         | Length of unit                                                             | (m)        | •                         |                        |                    |
|                                  | Width of unit                                                              | (m)        | •                         |                        |                    |
|                                  | Height of unit                                                             | (m)        | •                         |                        |                    |
|                                  | Length of required maintenance area                                        | (m)        | •                         |                        |                    |
|                                  | Width of required maintenance area                                         | (m)        | •                         |                        |                    |
|                                  | Space required for installation                                           | (m²)       | •                         |                        |                    |
| Refrigerant                      | Type of refrigerant                                                       | (-)        | •                         |                        |                    |
|                                  | Refrigerant charge                                                        | (liter)    | •                         |                        |                    |
|                                  | Toxicity                                                                  | (-)        | •                         |                        |                    |
|                                  | Flammability                                                              | (-)        | •                         |                        |                    |
| Operational parameters           | Type of heat source                                                       | (-)        | •                         |                        |                    |
|                                  | Range of functions (heating / domestic hot water / cooling)                | (-)        | •                         |                        |                    |
|                                  | Operation mode (monovalent / bivalent)                                    | (-)        | •                         |                        |                    |
|                                  | Temperature level of antifreeze                                           | (°C)       | •                         |                        |                    |
|                                  | Heat pump with integrated hot water tank                                  | (-)        | •                         |                        |                    |
|                                  | Volume of hot water tank                                                 | (m³)       | •                         |                        |                    |
| Cost                             | Capital cost                                                              | (€)        | •                         |                        |                    |
|                                  | Operational cost                                                          | (€)        |                           | •                      |                    |
| Temperature range                | Maximum flow temperature heating                                           | (°C)       | •                         |                        |                    |
|                                  | Minimum flow temperature heating                                          | (°C)       | •                         |                        |                    |
|                                  | Maximum flow temperature cooling                                          | (°C)       | •                         |                        |                    |
|                                  | Minimum flow temperature cooling                                          | (°C)       | •                         |                        |                    |
| Machine-specific parameters      | Total weight                                                              | (kg)       | •                         |                        |                    |
| Building automation              | Sound power level                                                         | (dB)       |                           | •                      |                    |
|                                  | Interface type to automation and control system                            | (-)        |                           |                        |                    |
4. Conclusion

In this paper, a process model and parameters for a data model for the design of geothermal heat pump systems were presented. BPMN was used to describe a standardized workflow and information flow for the design process. The process model shows that the interaction between different project participants is high. A data set with 76 geothermal heat pump parameters was compiled by analyzing different information sources. These parameters facilitate the design of the heat pump according to the requirements in different design stages. In BIM projects, these parameters can successively be adopted as attributes in the model. All parameters were thus assigned to design stages and rated according to their importance. The result shows that the degree of importance of the majority of parameters assigned to the first design stage (outline conceptual design) is classified as ‘high’. This underlines the importance of early design stages in MEP and BIM planning.

The presented process model and parameter set should support the set-up and management of BIM projects in which a geothermal heat pump is used as heating system for the building. This includes the creation of relevant BIM documents (e.g., employer’s information requirements, information delivery manuals etc.), the implementation and execution of rules for BIM model checking and the management of attributes in BIM models of geothermal heat pumps.

A next step would be to assign the identified parameters not only to design phases but also to specific use cases such as lifecycle analysis, building simulation, clash detection, BIM-based tenders etc. BuildingSMART Switzerland has recently introduced an online platform where such use cases are comprehensively described and documented. The methodology presented in this paper will subsequently be applied to other MEP components in order to build up a pool of MEP models which can be readily used in BIM projects.

Acknowledgements

The researchers would like to thank the four HVAC engineers for their contributed time to evaluate the process model and help to determine and rate the parameters of the geothermal heat pump. The work presented in this paper is part of the metaTGA project (FFG Grant No. 861729) funded in the framework of the program ‘Stadt der Zukunft’, which is a research and technology program of the Austrian Federal Ministry of Transport, Innovation and Technology. ‘Stadt der Zukunft’ is managed by the Austrian Research Promotion Agency (FFG) together with Austria Wirtschaftsservice Gesellschaft mbH and the Austrian Society for Environment and Technology (ÖGUT).

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