BauSIM 2024 in Wien
23. September – 26. September

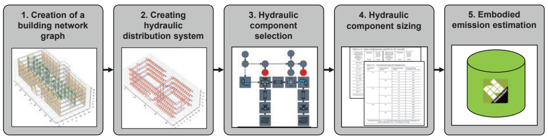
BIM-based Generation of Hydraulic Distribution Systems for Non-Residential Buildings

David Jansen[1], **Laura Maier**[1] & **Dirk Müller**[1]

[1]RWTH Aachen University, E.ON Energy Research Center,
Institute for Energy Efficient Buildings and Indoor Climate

Abstract

The Building Information Modeling (BIM) methodology has significant potential to enhance the efficiency and sustainability of building construction. An important step towards enhancing the sustainability of buildings is to reduce the embodied emissions in the building and its installed technologies. This poster presents a novel approach leveraging Industry Foundation Classes (IFC) data through the self-developed *bim2sim* process to design a full hydraulic distribution system and estimate its embodied emissions. By transforming the IFC geometry into a graph network and applying Steiner tree optimization (1), we develop an ecologically and economically optimized distribution system (2), including hydraulic component selection (3), sizing of these components (4) and embodied emission estimation (5). This approach not only automates the design processes but also contributes to the sustainability goals by providing an estimation of the embodied carbon emissions during the planning phase.



Introduction

With the ambitious goals to reduce the carbon emissions in the building sector, the embodied emissions in buildings become more important. Recent studies have shown that the heating ventilation and air conditioning (HVAC) domain accounts for up to 20 % [1, 2] of embodied emissions in non-residential buildings. In order to be able to better estimate these embodied emissions at an early planning stage and to optimize them in the future, this poster deals with the question:

How can we use early planning architecture IFC data for an automatic generation of the hydraulic distribution network and to estimate the associated embodied emissions?

Materials and Methods

The process for the hydraulic distribution system generation is shown in Figure 1.

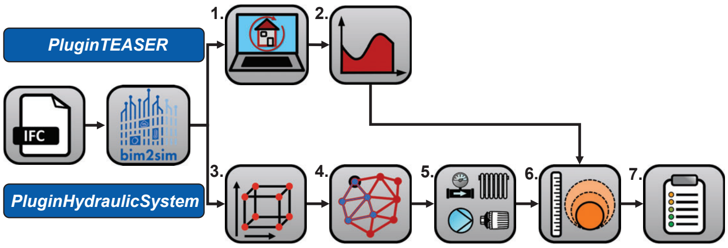


Figure 1: Methodology to generate the hydraulic distribution system.

The open-source framework *bim2sim*[1] is used to load the IFC of the building and process it for the following tasks. We use two plugins, the *PluginHydraulicSystem* that has specifically designed for this use case and the already existing *PluginTEASER*. The required steps are:

PluginTEASER

1. Create a parametric dynamic Modelica simulation model of the building using TEASER [3] and AixLib [4].
2. Calculate the heating demands of the building, which are relevant for the subsequent sizing of the components.

PluginHydraulicSystem

3. Generate a weighted graph network representation of the building, where distances are used as weights.
4. Create hydraulic strands for flow/return by using the Breadth-first search (BFS) and Steiner-Tree algorithms [5].
5. Place relevant components like thermostats, valves, etc. using the Lindenmayer-system [6].
6. Size all components based on the dynamic simulation results from step 2.
7. Output a final list of required components and masses and allocate equivalent carbon emissions by using data from ÖKOBAUDAT.

As the process of building simulation through the *PluginTEASER* of *bim2sim* will be described in a separate paper, this poster focuses on the methodology of the *PluginHydraulicSystem* and the steps 3-7.

Step 3: Weighted graph network representation of the building

As a use case for this poster, we use the Phantasy Office Building from KIT[2], shown in Figure 2. We start by extracting the global coordinates of `IfcSpaces`, `IfcWindows`, `IfcDoors`, and `IfcWalls` from the IFC file. The coordinates are converted into nodes of a graph network, with distances between them serving as edge weights. This generates the graph in Figure 3.

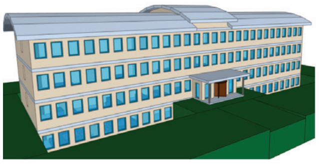


Figure 2: IFC of the Phantasy Office Building from KIT.

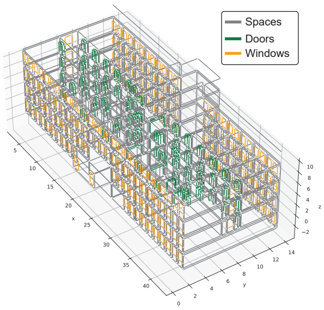


Figure 3: Graph network representation of building.

Step 4: Efficient strand layout for flow and return of hydraulic system

To create the strand layout for the hydraulic network multiple process steps are required:

- Define start and end nodes (Start node: Plant room, End nodes: Window nodes in each room)
- Calculate shortest paths between start node and all endpoints for each floor using the Steiner tree algorithm
- Convert graph to directed graph by using Breadth-First Search (BFS) algorithm
- Place radiators under windows and distributors on each floor

With these steps, the initial hydraulic distribution system shown in Figure 4 is generated.

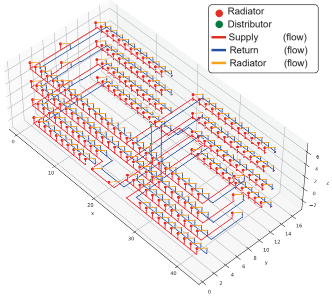


Figure 4: Created hydraulic network with supply and return strand.

Step 5: Relevant component placement

The *Lindenmayer System* is a mathematical formalism that was originally used to describe plants and their growth. The principle is based on production rules for strings, which are successively applied. We apply this concept to certain node types in the network graph, to place the required components for a working hydraulic system. An excerpt of the production rules is listed in Table 1. E.g., every node that is a `Distributor` will be replaced by a `Distributor` and a subsequent `Pump` to guarantee that every circuit is supplied by a pump.

Table 1: Lindenmayer rules for placing components in hydraulic network.

Node Type	Components
Distributor	Distributor → Pump
Energy Generator	Distributor → Check valve → Safety Valve
Radiator Supply	Thermostatic Valve → Radiator
Node with 3 neighbor Nodes	Distributor

Step 6: Component sizing

Radiator capacities are selected based on heating demands from building simulation, system temperature $T_{system} = T_{supply}/T_{return}/T_{room}$ and real available radiators (manufacturer data) by using DIN EN 442.

Pipe diameters are chosen based on maximum flow velocity and calculated volume flow rate derived from heating capacity of the radiators and system temperature T_{system} by using pipe table from DIN EN 105. The required insulation thickness is determined based on the outer diameter of the pipes.

Circulation pumps capacities are calculated based on a pressure loss analysis of the created hydraulic network. To do so, the pressure losses through pipes and components are calculated in each strand and the pump for each subsystem is sized based on the strand with the highest pressure loss.

Step 7: Mass calculation and carbon emission allocation

- Mass calculation for building materials like cement, glass, etc. based on IFC
- Mass calculation for piping network and its insulation as well as radiators and hydraulic components
- Embodied emission calculation using ÖKOBAUDAT database

Results and Conclusions

We simulate two construction variants and design their hydraulic networks for three different system temperatures T_{system}. Figure 5 displays the embodied emissions. As the building geometries are the same, while the building material and thus the heating demand changes, the hydraulic networks only differ in their sizing. Key conclusions are:

- Building materials significantly impact emissions compared to the hydraulic network.
- At higher system temperatures, piping and insulation dominate the emissions, while at lower system temperatures the radiators dominate.
- The lighter building has lower embodied emissions for both, building materials and hydraulics.

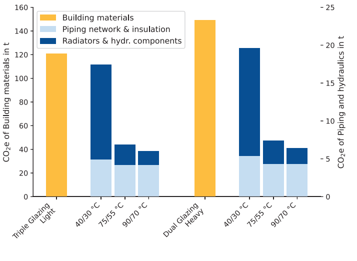


Figure 5: Embodied emissions for two construction variants.

Limitations

We have demonstrated that the methodology for automating hydraulic distribution system design using IFC data is effective. However, the following limitations exist:

- Only two construction variants of one building are simulated in this study. For general conclusions, more construction variants and more buildings need to be considered.
- Future work must also include the cooling supply as well as underfloor heating and duct systems, which also have a significant impact on HVAC emissions. Cooling is particularly important when considering windows with different heat transfer coefficients, as this can have opposing effects on heating and cooling requirements.

Acknowledgments

We gratefully acknowledge the financial support by the Federal Ministry for Economic Affairs and Climate Action (BMWK), promotional reference 3EN1050A.

References

[1] Alexander Hollberg, Deepshi Kaushal, Saso Basic, Alina Galimshina, and Guillaume Habert. A data-driven parametric tool for under-specified LCA in the design phase. In *IOP Conference Series: Earth and Environmental Science*, volume 588, page 052018. IOP Publishing, November 2020. Accepted: 2021-01-05T12:44:58Z ISSN: 1755-1315.

[2] Peter Ylmén, Diego Peñaloza, and Kristina Mjörnell. Life Cycle Assessment of an Office Building Based on Site-Specific Data. *Energies*, 12(13):2588, January 2019. Number: 13 Publisher: Multidisciplinary Digital Publishing Institute.

[3] Peter Remmen, Moritz Lauster, Michael Mans, Marcus Fuchs, Tanja Osterhage, and Dirk Müller. TEASER: An open tool for urban energy modelling of building stocks. *Journal of Building Performance Simulation*, 11(1):84–98, January 2018.

[4] Laura Maier, David Jansen, Fabian Wüllhorst, Martin Kremer, Alexander Kümpel, Tobias Blacha, and Dirk Müller. AixLib: An open-source Modelica library for compound building energy systems from component to district level with automated quality management. *Journal of Building Performance Simulation*, pages 1–24, 2023.

[5] Ivana Ljubić. Solving Steiner trees: Recent advances, challenges, and perspectives. *Networks*, 77(2):177–204, March 2021.

[6] Aristid Lindenmayer. Mathematical models for cellular interactions in development II. simple and branching filaments with two-sided inputs. 18(3):300–315.

---

[1] `https://github.com/BIM2SIM/bim2sim`

[2] `https://www.ifcwiki.org/index.php?title=KIT_IFC_Examples`